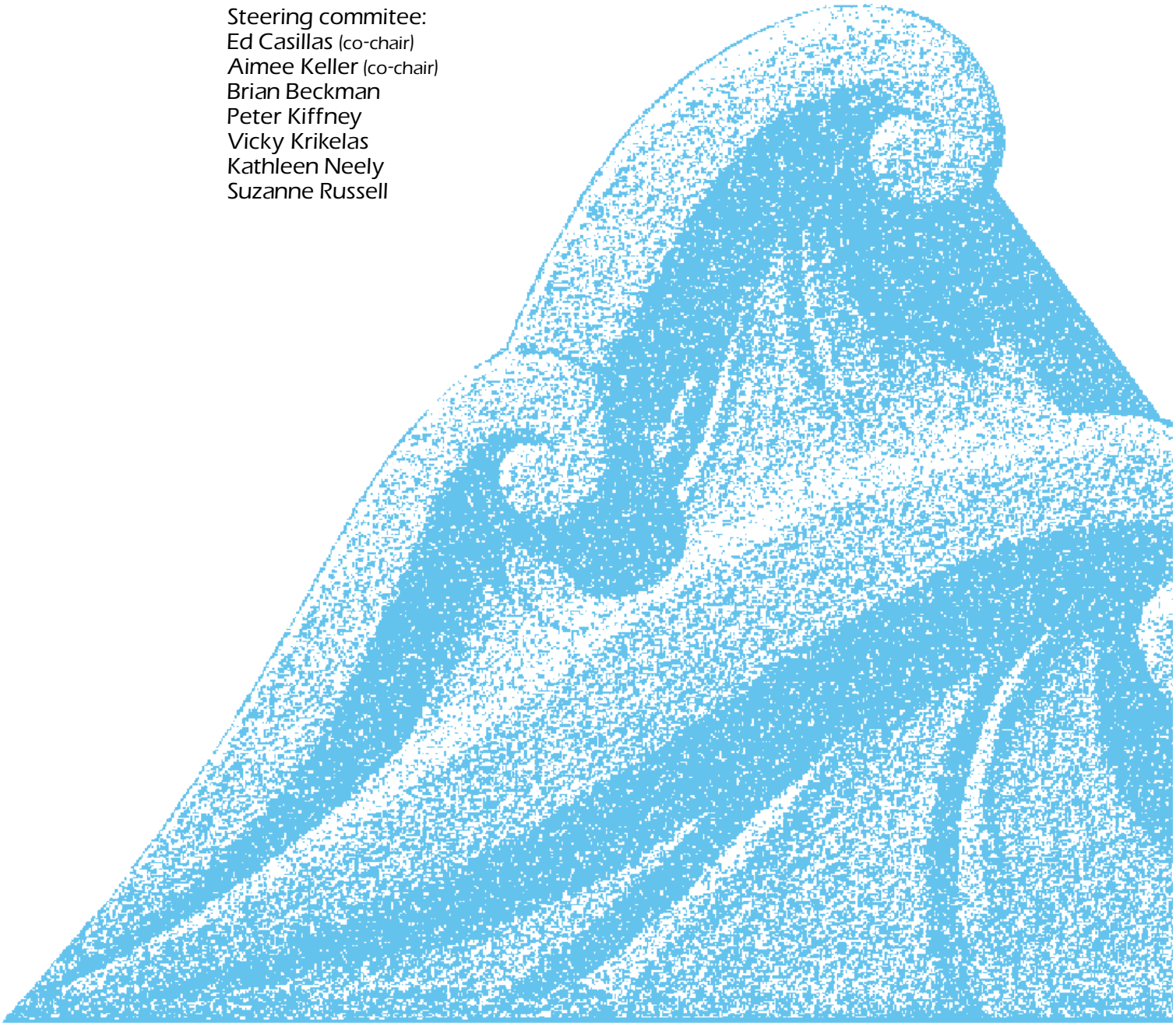
Northwest Fisheries Science Center

Proceedings of the Second Symposium

February 24-25, 2009
Seattle, Washington

Steering commitee:
Ed Casillas (co-chair)
Aimee Keller (co-chair)
Brian Beckman
Peter Kiffney
Vicky Krikelas
Kathleen Neely
Suzanne Russell



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Poster Presentations

Introduction

On 24–25 February 2009, the Northwest Fisheries Science Center (NWFSC or Center) sponsored the second Center-wide science symposium at the Montlake campus in Seattle, Washington. The goals of the symposium were to foster communication and collaboration among scientists at Montlake and all NWFSC field stations, as well as to showcase new and exciting areas of research.

Approximately 250 NWFSC scientists and staff attended the symposium, in addition to other NOAA staff and external collaborators. The two-day symposium consisted of a series of oral presentations and a poster session by NWFSC staff and scientists on topics highlighting climate change impacts and ecosystem-based management. The oral presentations included two rapid fire sessions on hot topics from the Center's five research divisions: Conservation Biology (CB), Environmental Conservation (EC), Fish Ecology (FE), Fishery Resource Analysis and Monitoring (FRAM), and Resource Enhancement and Utilization Technologies (REUT).

Symposium participants expressed an overwhelming appreciation for the information presented and the opportunity to collaborate with their colleagues.

Agenda

Day 1: Tuesday, February 24

8:00–8:10 a.m. Welcome (Usha Varanasi)

8:10–8:40 a.m. Keynote address (Michelle McClure)

Session 1: Climate Change

8:40–9:00 a.m. Restoration strategies to increase salmon resilience to climate change (Tim Beechie)

9:00–9:20 a.m. Predicting effects of climate change on freshwater stages of Columbia River salmon (Lisa Crozier)

9:20–9:40 a.m. Canaries in the sea: Monitoring physiological status of fish in the context of environmental conditions (Penny Swanson)

9:40–10:00 a.m. Tempo and mode: Possible effects of climate change on variability in ocean environments and salmon survival (Peter Lawson)

10:00–10:20 a.m. Climate impacts on harmful algal blooms in Puget Sound (Vera Trainer)

10:20–10:40 a.m. Break

Session 2: Research Highlights I

10:40–11:00 a.m. Multivariate characterization of anadromous and resident *Oncorhynchus mykiss*: Three dam scenarios (Gary Winans)

11:00–11:20 a.m. The role of the Columbia River estuary in salmon recovery (Daniel Bottom)

11:20–11:40 a.m. A novel approach for estimating the ages of cetaceans using blubber fatty acid compositions of biopsy samples (Gina Ylitalo)

11:40–12:00 p.m. How noise exposure affects the vocal behavior of Southern Resident killer whales (Marla Holt)

12:00–12:20 p.m. Home range size and patterns of space use by lingcod, copper rockfish, and quillback rockfish in Puget Sound in relation to diel and tidal cycles (Nick Tolimieri)

12:20–1:00 p.m. Lunch

Session 3: Ecosystem Research

1:00–1:20 p.m. Quantitative approaches for identifying species interactions and resilience in marine ecosystems (Mark Scheuerell)

1:20–1:40 p.m. An ecosystem-scale assessment of abundance, life history, and genetic diversity of steelhead (*Oncorhynchus mykiss*) in Hood Canal, Washington (Barry Berejikian)

1:40–2:00 p.m. Ecosystem services provided by the nearshore in Puget Sound: An analysis of change (Anne Guerry)

2:00–2:20 p.m. A descriptive example of applying vulnerability evaluation criteria to California nearshore species (Jason Cope)

2:20–2:40 p.m. A regional effort to select environmental indicators for the Puget Sound (Sandie O'Neill)

2:40–3:00 p.m. Break

Session 4: Rapid Fire I (3:00–4:30 p.m.)

Molecular correlates of olfactory imprinting in Pacific salmon (Andrew Dittman)

Voucher specimen collections for deep-water corals and marine fishes (Ewann Berntson)

Evaluating the microbial composition of the sea surface microlayer and killer whale breath (Linda Rhodes)

Reproductive parasitism of lithodid crabs by snailfishes off the western United States (Keith Bosley)

A summary of acoustic tagging programs for migratory and resident Chinook salmon in Puget Sound (Anna Kagley)

Residence time of juvenile Chinook salmon in the Columbia River estuary (Regan McNatt)

Toxic contaminants and juvenile salmonids in the lower Columbia River and estuary (Lyndal Johnson)

Pacific salmon on the brink of ocean entry: New insight from the Columbia River estuary (Laurie Weitkamp)

Evaluating ecological and economic impacts of individual quotas for the groundfish trawl fleet (Isaac Kaplan)

Assessing institutional designs for managing water supplies across the Puget Sound (Karma Norman)

Restoration of salmon habitat in tidal wetlands habitat: An example from the Grays River tributary of the lower Columbia River (Curtis Roegner)

Improved flatfish health following remediation of a Superfund site (Mark Myers)

Day 2: Wednesday, February 25

Session 5: Research Highlights II

8:30–8:50 a.m. Hatchery induced life history variation in Columbia River Chinook salmon (Don Larsen)

8:50–9:10 a.m. The promise and pitfalls of using climate data in fish stock assessment (Melissa Haltuch)

9:10–9:30 a.m. Acoustics: An advanced remote sensing technology in fisheries surveys (Dezhang Chu)

9:30–9:50 a.m. Ecosystem dynamics in the northern California Current: Effects on juvenile salmon (Ric Brodeur)

9:50–10:10 a.m. The enigma of *Vibrio parahaemolyticus* outbreaks in the Pacific Northwest (Rohinee Paranjpye)

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Session 6: Rapid Fire II (10:30–11:30 a.m.)

Acoustic tracking of hatchery reared lingcod in Puget Sound (Jonathan Lee)

Early marine survival and behavior of steelhead (*Oncorhynchus mykiss*) smolts through Hood Canal and the Strait of Juan de Fuca (Megan Moore)

Pesticides as a limiting factor for salmon recovery in the western United States (Nat Scholz)

Super crunching multispecies monitoring data (Eli Holmes)

Effects of temperature change on demersal fishes in the California Current: A bioenergetics approach (Chris Harvey)

Rebuilding depleted West Coast groundfish species: Management actions and early results (Jim Hastie)

Known unknowns now known: The fish heart as a target for the long-term impacts of oil spills (John Incardona)

Using PIT tag technologies to investigate adult salmonid straying in the lower Columbia River (Sandra Downing)

11:30–1:00 p.m. Lunch and Poster Session

Oral Presentations

Restoration strategies to increase salmon resilience to climate change

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Climate change will affect many aspects of Pacific salmon (*Oncorhynchus* spp.) habitat including flow regimes, water temperature, ocean productivity, land cover, pathogens, food webs, and water quality. However, anticipated habitat changes and salmon life histories vary greatly across the geographic range of salmon, so salmon populations are not all equally susceptible to climate change. Moreover, causes of habitat degradation vary among rivers, so options for conserving robust salmon populations must be evaluated in the context of each watershed and population's sensitivity to climate change. Both of these factors—the relative susceptibility of populations to future climate and the likely impacts of management strategies in different areas—are key for prioritizing actions aimed at protecting and restoring salmon under a changing climate. This study addresses two questions that must be answered to develop effective salmon conservation strategies across their range. First, which salmon populations or metapopulations are most sensitive (or conversely, most resilient) to climate change? Second, what management strategies and conservation actions will most benefit salmon populations under alternative climate futures?

We address the first question by ranking population sensitivity to climate change based on current and historical salmon population status for abundance, productivity, spatial structure, diversity, the effects of habitat degradation, and climate change scenarios for in stream flow and water temperature. We are first conducting a pilot study on populations in the Columbia River basin, using existing data from landscape and population analyses conducted in the contexts of salmon recovery planning and the Federal Columbia River Power System Biological Opinion. Once we have developed the ranking methodology, we will then expand the analysis to the full range of salmon using correlated but coarser resolution data sets for the three key ranking criteria—predicted climate change effects, salmon population status, and current habitat degradation.

We address the second question using salmon population modeling to evaluate the likely outcome of alternative restoration strategies combined with shifting habitat conditions due to climate change. These analyses will be conducted on a limited number of watersheds and salmon species spread across latitudinal ranges of salmon (Sacramento River to Yukon River). Outcomes of these analyses will identify region-specific restoration strategies that are most likely increase salmon resilience to climate change.

Predicting effects of climate change on freshwater stages of Columbia River salmon

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Climate affects organisms through an intricate web of ecological interactions and evolutionary responses, all mediated by local habitats. We have explored some of these interactions and population-specific environmental sensitivities in Columbia River salmon. Because of the complex life history of salmon, each life stage confronts different environmental challenges. Recognizing this complexity, we have focused on identifying life-stage-specific and population-specific responses of Columbia River spring and summer Chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) to variation in climate.

Using a unique, 18-year PIT-tag study of 13 Snake River Chinook salmon populations, we identified strong but complex effects of variation in temperature and flow on juvenile growth and survival. At low fish densities, temperature correlated positively with parr length, but higher fish densities reduced or reversed this relationship. All of the 13 populations studied exhibited this pattern. Populations differed, however, in the sensitivity of parr-to-smolt survival to environmental conditions. Fall flow was the most important environmental predictor of survival for most populations, but summer temperature was highly significant in some cases, especially at lower elevations. We linked these patterns in survival with hydrological projections of climate change in these streams, and used life cycle models to evaluate potential consequences of climate change for population viability. Scenarios of climate change produced declines in abundance and increases in extinction risk in all populations, but the relative risks among populations depended on the climate change scenario.

Shifting our focus to the adult stage, we explored the history of upstream migration timing in sockeye salmon. Sockeye salmon now enter the lower Columbia River 10 days earlier, on average, than they did in the 1930s. Based on a model of the potential effects of river temperature on migration survival and a simulation of historical selection pressure, we argue that this change reflects both evolutionary and plastic responses to rising river temperatures. We conclude that climate change can have both positive and negative effects on salmon, but the net effects depend in part on the responses of other species to environmental change. Salmon will adapt to climate change, but the limits to adaptation are unknown. Ultimately, the extent of climate change will determine which life history types remain viable in the Columbia River basin.

Canaries in the sea: Monitoring physiological status of fish in the context of environmental conditions

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The status of fish populations is generally monitored in terms of number of individuals and characteristics such as body size, age of maturity, and genetic diversity. These characteristics generally reflect how fish are adapting to environmental change over long periods of time. However, more in-depth analyses of the physiological status of individual fish in the context of environmental variables can yield valuable information on the quality of the habitat and future life history decisions. To this end, we have developed and validated a variety of endocrine and molecular tools to monitor growth, reproduction, and stress in salmonid fish that may be useful for a variety of marine fish species.

A combination of laboratory and field studies have shown that plasma levels of a growth factor (IGF I) can be used as a growth index in juvenile salmon. Levels of sex steroids have been used to identify individuals that are maturing as much as 12 months before spawning, well in advance of obvious changes in gonad morphology or size. This information has been used to determine precisely when salmon are initiating maturation in a given year so that we can better understand what environmental factors may be influencing this critical life history decision.

We have also taken a targeted gene approach to identify transcripts for reproductive genes that are altered in response to environmentally relevant concentrations of estrogenic chemicals and that could be incorporated into current programs that monitor juvenile salmon for exposure to environmental estrogens. Aims of current and future work are to develop more comprehensive molecular markers of cell growth, cell death, and reproductive status that can be used on tissue biopsies to assess physiological status of salmon in relation to environmental variables in field studies.

Tempo and mode: Possible effects of climate change on variability in ocean environments and salmon survival

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Many climate change studies have explored the likely physical and biological effects of rising temperatures on salmon runs and a variety of other species. Less attention has been paid to another likely effect of climate change: increasing variability. We are starting to see evidence of changing patterns of interannual variability in ocean environments. Given the sensitivity of salmon populations to ocean conditions, we would expect to see accompanying changes in patterns of salmon survival.

We use 10-year moving standard deviations to look for changes in variability in major ocean climate indices and in salmon populations from Alaska to California. Patterns vary widely, but there is a strong indication of increased variability in large-scale climate indices such as the Pacific Decadal Oscillation. Many, but not all, salmon populations also show increasing variability in escapements. Climate-driven patterns in salmon can be difficult to identify, as they are confounded by other anthropogenic factors including harvest, hatchery practices, and habitat alterations. If environmental variability is indeed increasing, we would expect to see it in freshwater as well as marine environments. This would challenge salmon populations' ability to respond and places increasing importance on maintaining genetic and life history diversity in salmon runs. Population viability models often include variability, based on historical observations, as a risk factor. Increasing variability would increase risk to salmon populations and should be accounted for in assessing viability.

Climate impacts on harmful algal blooms in Puget Sound

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The influence of weather and climate variations on harmful algal blooms of *Alexandrium* in Puget Sound was investigated using observations of shellfish toxicity from 1957 to 2007. *Alexandrium* produce potent neurotoxins called paralytic shellfish toxins (PSTs) that accumulate in filter-feeding shellfish and threaten human health. We used concentrations of PSTs in shellfish tissues as a proxy to describe *Alexandrium* bloom dynamics and examine the influence of climate on daily, interannual, and interdecadal timescales.

A combination of low stream flow, weak surface winds, and small tidal variability appears to precede sound-wide PST events. This combination of environmental conditions typically occurs in early fall following seasonal warming of sea surface temperatures over the summer. On longer timescales, shellfish toxicity covaries with warm phases of the Pacific Decadal Oscillation (PDO) and the window of optimal growth conditions for *Alexandrium* as determined by sea surface temperatures exceeding 13°C. However, no robust relationship exists with warm phases of the El Niño Southern Oscillation (ENSO). This is because warm winter temperature anomalies during warm ENSO events do not persist long enough to overlap with the annual time period that shellfish accumulate PSTs in Puget Sound, which is typically from July through November.

In contrast, warm winter temperature anomalies during warm phases of the PDO persist for four to five seasons or more with re-emergence the following year. By extrapolating mechanisms leading to shellfish toxicity on smaller and more localized scales, we predict that rising water temperatures associated with the regional impacts of anthropogenic global warming may promote earlier and longer lasting PST events in Puget Sound in the future.

Multivariate characterization of anadromous and resident *Oncorhynchus mykiss*: Three dam scenarios

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Fish isolated behind major dams in the northwest United States have undergone differentiation for 80+ years. As these dams are removed or bypassed, resident rainbow trout (*Oncorhynchus mykiss*) upstream will be exposed to anadromous populations of *O. mykiss* (steelhead). How rainbow trout will interact with steelhead is an important question to consider in conservation and management circles. Precise characterization of both gene pools is paramount prior to dam removal or bypass to follow the interaction of the two life history types.

I presented an overview of our studies of *O. mykiss* in six river systems in the Columbia River and Puget Sound basins (including Icicle Creek, Wenatchee River, White Salmon River, Little Sandy River, Lewis River, Green River, and Elwha River). Results for three dam sites were provided. To describe the level and patterns of differentiation of gene pools above and below dams, we used 15 microsatellite loci, 2 major histocompatibility loci, and morphological characteristics (body shape and coloration patterns). These results can be used to understand rates of character differentiation and adaptation, to monitor population recolonization, and to recognize and conserve not only critical populations but also unrecognized "gems" in river restoration projects.

The role of the Columbia River estuary in salmon recovery

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In 1999 NOAA Fisheries Service organized a team of researchers to review the status of knowledge about the estuarine ecology of Columbia River salmon and the potential role of the estuary in salmon population decline and recovery. The results of this review, summarized in the Salmon at River's End report (NOAA Tech. Memo. NMFS-NWFSC-68), hypothesized that historic habitat losses had 1) reduced rearing opportunities for salmon, 2) simplified salmon life history diversity, and 3) reduced the contribution of wetland and other macrophytic plants to estuarine food webs, potentially decreasing the estuary's capacity to support juvenile salmon.

From 2002 to 2007 we conducted new studies to investigate salmon distribution and habitat use in the estuary and to evaluate the report's hypotheses. Our results confirm that salmon rearing opportunities in the lower estuary have decreased substantially during the last century, while hatchery programs, watershed modifications, and other changes likely have simplified historical patterns of estuarine migration and residency by juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Nonetheless, we have documented significant variation in Chinook salmon life histories, longer-than-expected estuarine residence times (even among some upper basin stocks), and strong selection by salmon for carbon sources that are linked to wetlands and other shallow estuarine habitats.

Genetic analyses revealed that all Columbia River evolutionarily significant units are capable of expressing estuarine-resident life histories, although the patterns of estuarine habitat use may vary among genetic stock groups. The estuary's role as a nursery ground for stocks throughout the basin suggests that restorative actions above Bonneville Dam alone will not be sufficient to meet salmon recovery goals or to ensure population resilience in a changing environment. However, restoration needs throughout the upper estuary (RKM 100 to Bonneville Dam), where wetland and floodplain habitat losses are extensive and stock-specific habitat use has not been investigated, remain poorly understood. An important question for future ecosystem management is whether hydrological and other changes have caused the ecosystem to cross an ecological threshold that could resist future estuary restoration and salmon recovery efforts.

A novel approach for estimating the ages of cetaceans using blubber fatty acid compositions of biopsy samples

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Information on the age distributions of cetacean populations is important in assessing their status and long-term viability. Current methods of ageing cetaceans rely either on limited longitudinal sighting studies of individual animals from the birth year or on postmortem procedures to extract tissues suitable for age determination. Here we describe a method for estimating the ages of live, free-ranging eastern North Pacific killer whales (*Orcinus orca*), as well as humpback whales (*Megaptera novaeangliae*) from the northwest Atlantic and Southeast Alaska, using low impact biopsy sampling techniques. Specifically, shallow outer-blubber samples were obtained from known-age whales and analyzed for lipid class and fatty acid (FA) compositions.

Individual short-chain, branched-chain, and odd-chain FAs correlated better with age for transient and resident killer whales of both sexes than did wax/sterol esters, but these single parameter relationships were population specific, moderately scattered, and varied with long-term diet. We found that, independent of whale age, diet and ecotype, the ages of individual animals could be predicted with good precision ($\sigma = \pm 3.8$ years) using a simple, multilinear equation model derived from the combination of two specific FA ratios. For humpback whales, four multilinear FA-age models were developed, using exact known-age animals or exact age plus minimum known-age whales from two distinct populations. Each of these empirical models was based on a linear combination of FA ratios (two specific FA ratios per model), rather than their individual FA compositions, and each appeared to be largely independent of sex, diet, and nutritional status.

Although the precision of these models was somewhat variable, our findings suggest that it should be possible to estimate the age of an individual humpback whale with better than decadal resolution using this approach. Based on these findings, it is our intention to explore the possibility of using this novel approach to estimate the ages of other species of cetaceans and pinnipeds, particularly for remote populations that have not been continuously observed.

How noise exposure affects the vocal behavior of Southern Resident killer whales

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Marine mammals use sound for foraging, breeding, predator avoidance, and coordinating group movement. Noise exposure has the potential to interfere with the reception and use of these sounds. Killer whales (*Orcinus orca*) produce a variety of acoustic signals including echolocation clicks to detect prey and calls for communicative functions. Call production and exchange is believed to function to coordinate movement among group members when individuals are dispersed and foraging.

The inland waters of Washington state and British Columbia are important summer and fall foraging areas for Southern Resident killer whales, where a variety of vessels and other sources of anthropogenic noise are also prevalent. Vessel noise can mask or cover up the calls that killer whales produce because the frequency range of noise emitted from nearby vessels overlaps the frequency range of killer whale calls. Individuals may compensate for background noise by changing their signal's amplitude, duration, repetition rate, or frequency. Such vocal compensation is often interpreted as an antimasking strategy for high background noise levels.

The goal of this study was to investigate call amplitude compensation (the Lombard effect) in these killer whales to elucidate how they might compensate for changing levels of background noise in the marine environment and how vessel numbers contribute to noise exposure in this population. Additionally, behavioral data observed at the surface were collected to determine how the use of different acoustic signals corresponded with group activity states. This information is useful to infer events such as foraging using remote acoustic monitoring and also to determine how noise exposure might affect the activity states of the whales.

Data were collected in waters surrounding the San Juan Islands during the summer months using a calibrated recording system. We used multiple hydrophones to determine the range at which calls were produced and then calculated call source levels and background noise levels in the 1–40 kHz band. Call source levels were positively correlated with background noise levels and the slope of the fitted linear regression line indicated that whales increased their call amplitude by 1 dB for every dB increase in background noise levels.

Motorized vessels within 1,000 m of the recording device explained 45% of the variation in background noise levels. The upper range of background noise levels corresponded to approximately 45 nearby vessels. Sound production patterns compared by behavioral states illustrated that calling rates as well as the presence of fast and slow clicks were significantly higher when whales were foraging compared to when they were traveling. These results indicate that not only echolocation clicks but also communicative signals are particularly important to foraging whales that are faced with the challenge of hearing these signals in anthropogenic noise.

Home range size and patterns of space use by lingcod, copper rockfish, and quillback rockfish in Puget Sound in relation to diel and tidal cycles

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For marine fishes, the estimation of home range size has received attention recently because of its application to the design of marine reserves. How individuals use space may also be important to the management of the species or for understanding behavioral processes like optimal foraging or territoriality. We used an acoustic tracking system (VRAP) to examine patterns in home range size and movement behavior for three demersal fishes in Puget Sound: lingcod (*Ophiodon elongatus*), copper rockfish (*Sebastes caurinus*), and quillback rockfish (*S. maliger*). Data were collected over eight weeks in the summer of 2006.

Home ranges were relatively small (≈1,500 to 2,500 m^2) and did not differ among species. However, lingcod had larger home ranges during the day than at night. Movement in all three species was in some way related to diel and tidal cycles, although individuals within species differed, and there was no general pattern. For example, about one-half of the lingcod used particular portions of their home ranges only during the day and on the flood tide. However, other individuals did so on the ebb tide. Some copper rockfish moved to specific areas of their home range on the day ebb tide, while others did so on the night flood tide and others showed no pattern. Similar results were seen for quillback rockfish. The individual variation in movement behavior is the most interesting aspect of the results. Failure to incorporate this variation into ecological models ignores the individual level variability upon which natural selection operates.

Quantitative approaches for identifying species interactions and resilience in marine ecosystems

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Scientists and policy makers often rely on models to improve their understanding of marine ecosystems and effectively manage fisheries resources. Mechanistic models (e.g., Atlantis, EcoSim) utilize functional relationships and empirical data on diets in an attempt to recreate food web dynamics. In systems where information on diet and functional relationships is missing, or they change over time as environmental conditions change, the development of mechanistic ecosystem models typically proves challenging and requires assumptions that are difficult to validate with data.

Over the past decade, however, quantitative ecologists have been developing and applying an alternative approach to ecosystem modeling. This statistical method is based on modeling time series of species abundances produced by biological interactions and the physical-chemical environment rather than modeling the underlying mechanisms themselves. By using a set of multivariate auto-regressive (MAR) equations as an approximation to nonlinear, stochastic community dynamics, one can estimate the strength of interaction among various species and compare them to the relative effects of environmental drivers (e.g., temperature, contaminants) in structuring the ecosystem.

This allows for the identification of important (i.e., keystone) species toward which management efforts might be concentrated. Furthermore, various stability properties can be calculated and used to assess ecosystem resilience to environmental and anthropogenic disturbances. We discussed how we have applied MAR models to freshwater ecosystems and are advancing their development and application in the Puget Sound and California Current ecosystems.

An ecosystem-scale assessment of abundance, life history, and genetic diversity of steelhead (*Oncorhynchus mykiss*) in Hood Canal, Washington

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In 2006 we initiated an ecosystem-scale hatchery experiment in the Hood Canal to determine the effects of steelhead (*Oncorhynchus mykiss*) hatchery programs on Endangered Species Act–listed natural populations. The study involves monitoring abundance, genetics, and life history diversity in three supplemented and four nonsupplemented natural populations before, during, and after hatchery fish begin spawning in any of the streams. This presentation reported preliminary data from the presupplementation phase of the project to characterize the "natural" condition of Hood Canal *O. mykiss* populations.

Flow and temperature and geologic profiles of Hood Canal streams vary widely. Eastside lowland streams (Big Beef Creek, Dewatto River, Tahuya River) are typified by lower flows (particularly in the summer), higher temperatures, and a decreasing flow through the winter and spring. Western streams draining the Olympic mountains (Little Quilcene, Dosewallips, Duckabush, Hamma Hamma, and Skokomish) are steeper, colder, have increasing spring flows associated with glacial or snow melt runoff, and all but one (Skokomish) have barriers to anadromous fish migration.

Adult abundance (based on redd surveys) is strongly, positively correlated with stream length ($R^2 = 0.87$), but not mean flow ($R^2 = 0.24$) or annual cumulative temperature units ($R^2 = 0.01$). Abundance has been fairly stable in all streams over the past 15 years. Streams without barriers to anadromous migration support adult populations that are approximately twice as dense (number of redds per mile) as populations with anadromous barriers that support rainbow trout (*O. mykiss*) populations above and below the barriers. Otolith microchemistry data suggest that juvenile *O. mykiss* in nonbarrier streams were spawned almost exclusively by anadromous (i.e., steelhead) females, whereas significant proportions of parr from the anadromous-accessible

reaches of the barrier streams (Hamma Hamma, Duckabush, and Dosewallips) were spawned by residents (i.e., rainbow trout females).

Analyses of microsatellite DNA data show significant genetic differentiation between east side and west side populations. The Hamma Hamma River also shows further differentiation from other west side populations. Resident and anadromous *O. mykiss* within the same river were genetically more similar to each other than to samples of the same life history type from different rivers.

Despite the large variation in watershed characteristics and habitat quality throughout the Hood Canal, all populations appear to be in a depressed state (fewer than eight redds per km). Early marine survival estimates obtained through acoustic telemetry monitoring suggest that mortality during the first two to three weeks after seawater entry may be a common factor limiting the productivity of steelhead populations throughout Hood Canal.

Ecosystem services provided by the nearshore in Puget Sound: An analysis of change

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In principle, the framework of ecosystem services (benefits that people obtain from ecosystems) can inform ecosystem approaches to managing coupled social-ecological systems such as Puget Sound. However, the transition from theory to practice is challenging. Making ecosystem services a useful concept to Puget Sound ecosystem management requires basic research on how services vary across the region and how they might be affected by alternative management schemes.

We examined a diverse suite of ecosystem services that are derived from nearshore marine habitats across the Puget Sound region and modeled how changes in the nearshore are likely to affect the flows of those services. First we outlined the scope of our program, summarizing the range of services within our purview and the ways in which we are modeling them. Then we discussed model results from some key services (e.g., the provisioning of seafood and carbon sequestration by eelgrass). Throughout we emphasized three key themes: 1) the utility of modeling change in ecosystem services under alternative management scenarios, rather than tallying static ecosystem services and their values; 2) the importance of incorporating spatially explicit information into ecosystem-service modeling; and 3) the benefit of close interdisciplinary collaboration between economists and ecologists undertaking ecosystem services work.

A descriptive example of applying vulnerability evaluation criteria to California nearshore species

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In light of ongoing crises in fisheries and marine ecosystem management, a growing body of literature has highlighted the need for biologists and resource managers to develop and apply methodologies that are capable of identifying species or populations at greater risk of overexploitation and extirpation. One increasingly popular approach is a productivity and susceptibility analysis (PSA), originally developed for Australian prawn fisheries, in which the vulnerability of a given stock is based on a combination of the estimated or perceived productivity of the stock plotted against the susceptibility to overfishing. This presentation provided an example of this type of analysis developed for the 19 species included in the California Nearshore Fishery Management Plan (NFMP). The methodology is based on a version of the PSA approach being developed by the NOAA Fisheries Service Vulnerability Evaluation Working Group, which is currently in the process of preparing draft technical guidance for conducting vulnerability assessments for species managed under fishery management plans implemented by the regional fishery management councils.

Results of this case study in particular indicate that the more vulnerable species in the NFMP include China (*Sebastes nebulosus*), copper (*S. caurinus*), quillback (*S. maliger*), and blue rockfishes (*S. mystinus*), of which only the latter has been evaluated in a formal stock assessment. More importantly, we suggest that additional and more rigorous analysis of these or of other species, managed by either the State of California or the Pacific Fishery Management Council (or both), may aid managers and stakeholders in setting research and assessment priorities, considering management alternatives and strategies, developing or revising species assemblages for multispecies management systems, and evaluating how precautionary catch limits should be based.

A regional effort to select environmental indicators for Puget Sound

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The Puget Sound Partnership (PSP) is developing an action agenda to serve as a roadmap for restoring and maintaining the health of Puget Sound. To evaluate progress towards their goals, NOAA led a regional effort to identify a robust, integrated set of environmental indicators to characterize and communicate information about six components of the Puget Sound ecosystem (species and food webs, habitat and processes, water quality, water quantity, human health, and human well being). Developing quantified outcomes and performance standards for environmental indicators takes several years, so, to meet the short timeline for developing the action agenda, a tiered two phase process was developed to inform policies and management actions both immediately (Phase 1) and in the longer term (Phase 2). The objectives of the Phase 1 indicator's project were to develop a consistent set of criteria and framework for evaluating environmental indicators, to create conceptual models that define key structures and functions of the Puget Sound ecosystem, and to then select the most suitable "recommended available indicators" from a list of existing indicators. Additional work will be necessary in Phase 2 to develop new indicators.

For Phase 1, a hierarchical decision tree was selected for evaluating individual indicators that grouped selection criteria into five evaluation questions: Is the indicator conceptually valid? Do data exist? Can the indicator be feasibly implemented? Are the statistical properties understood and sufficient? Does the indicator fulfill management and reporting needs? Additionally, two frameworks were identified that collectively assist with identifying the suite of indicators necessary to track the health of the Puget Sound ecosystem, one that reflect properties of a functioning ecosystem, and one that attempts to address causal mechanisms underlying ecosystem function. The Environmental Protection Agency's list of Essential Ecological Attributes was used to assess and report on ecological conditions. A Driver-Pressure-State-Impact-Response (DPSIR) causal chain framework was used to define the causal links or relationships between ecosystem attributes we can measure and aspects of the ecosystem that have high relevance to humans. A DPSIR framework was also chosen as the common framework to develop several component-based conceptual models.

Based on these criteria and framework and conceptual models, a nonprioritized list of indicators was selected for further consideration by PSP. The use of the selected indicators will depend upon the specific assessment questions and strategies put forward by PSP and its intended uses. The provisional indicators serve as a tangible starting point for dialogue between policy and science, placeholders until final indicators are identified. The final suite of indicators to be selected in Phase 2 will draw from the preapproved provisional indicator list and new indicators that will be developed using the criteria/framework and conceptual models from Phase 1. The final suite of indicators should include state and impact indicators that inform us about the

seriousness of the problems and response and pressure indicators that tell us how best to fix them.

Molecular correlates of olfactory imprinting in Pacific salmon

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Pacific salmon (*Oncorhynchus* spp.) are well known for their extraordinary homing migrations from oceanic feeding grounds back to their river of origin to spawn. These migrations are governed by olfactory discrimination of homestream odors that juvenile salmon learn (imprint to) prior to their seaward migrations.

Successful homing requires that salmon experience homing cues during sensitive periods for imprinting. Our previous studies have suggested that during imprinting, the peripheral olfactory system is sensitized to specific homestream odorants. In our program we are hoping to exploit this sensitization to develop cellular or molecular markers that are correlated with olfactory imprinting to identifying important developmental periods and environmental influences important for successful imprinting. As part of this sensitization process, we have shown that specific olfactory receptors are upregulated in response to odorant exposure. Specifically, we are studying expression of a candidate odorant receptor for L-arginine, a potent salmon odorant, during the process of imprinting. Using a combination of molecular, physiological, and behavioral assessments, we have demonstrated that salmon exposed to L-arginine during appropriate developmental stages demonstrated long-term memory formation for this imprinting odorant ($P \leq 0.05$, two-sample t-test).

Treatment groups that successfully imprinted, as evidenced by adult behavior, also demonstrated increased expression (relative to arginine-naïve fish) of the putative arginine receptor mRNA in the olfactory epithelium. Our results suggest that early odorant exposure may affect olfactory receptor expression throughout the life of a salmon and these receptors may provide a molecular marker for imprinting success. Ultimately, we hope to use these markers to aid in developing management and land use practices that ensure successful imprinting and will minimize straying by hatchery and wild fish.

Voucher specimen collections for deep-water corals and marine fishes

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We are developing an initial species inventory of deep-sea corals off the northeast Pacific coastline as a necessary first step to understanding more about the ecology and distribution of deep water corals. To facilitate species identification, we are creating a DNA sequence repository in collaboration with Fisheries and Oceans Canada and NOAA's Alaska Fisheries Science Center. All DNA sequences will be linked to verified morphological identifications to create a west coast repository of coral species found in this area. This repository will serve not only as an essential resource for coral researchers and other stakeholders, but also as a foundation for future research efforts at the NWFSC aimed at understanding the biogeography and ecology of coral species in these deep-sea communities. Two genes from each specimen will be sequenced: COI for submission to the DNA Barcode of Life, and mitochondrial MutS. This sequence information will allow us to make a preliminary identification based on genetics, and thereby group like individuals to reduce the number of individuals needed to send to morphological taxonomists already overwhelmed with their workloads.

Our preliminary results indicate that specimens recovered opportunistically from trawl surveys are of sufficient quality to give clean genetic sequences. Initial shipboard identifications are made by volunteers given minimal training in identification of corals, so it is critically important that reference material supplied to them be clear and accurate. Our sequencing and identification efforts will help provide the most up-to-date information regarding the genera and species likely to be found off the northeast Pacific coastline. We have already demonstrated instances where initial shipboard identifications were accurate, as well as those where initial species designations were inaccurate or of insufficient detail. The combination of MutS sequences, species specific for many octocorals but not found in hexacorals, plus COI which is found in all coral species, should yield sufficient power for identifying all taxa present in our regional waters.

I also briefly described our collaboration with the University of Washington Fish Collection to develop a marine fish species voucher archive linked to molecular genetic data for species identification. As with the corals, the COI data we generate for these vouchers are submitted to the Barcode of Life.

Evaluating the microbial composition of the sea surface microlayer and killer whale breath

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The sea surface microlayer (SML), the interface between the atmosphere and ocean, is a distinct aquatic environment. The SML is enriched in dissolved organic matter, lipids, and microbial communities compared to underlying pelagic seawater. Cetaceans such as killer whales (*Orcinus orca*) intersect the SML when breathing, offering a route for respiratory exposure.

This study evaluated the microbial composition of SML in waters inhabited by endangered Southern Resident killer whales and the exhaled breath of proximal individual killer whales over a 3-year period during summer and fall. SML and exhaled breath were cultured on selective media, and bacterial and fungal isolates were taxonomically classified to at least the genus. Bacterial isolates from exhaled breath were ribotyped and tested for resistance against a panel of eight antibiotics. Human pathogens, such as *Clostridium perfringens* and *Pseudomonas aeruginosa*, were isolated from SML, and antibiotic-resistant *Salmonella enterica* Heidelberg and *Vibrio alginolyticus* were isolated from exhaled breath.

Multidimensional scaling identified similarities between microbial composition and geography, suggesting potential spatial influences. This study demonstrates that evaluation of SML and

exhaled breath offers an opportunity to monitor killer whale health in the context of environmental influences.

Reproductive parasitism of lithodid crabs by snailfishes off the western United States

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The FRAM Division has conducted annual bottom-trawl surveys along the West Coast since 1998. Though the primary mission of the surveys is to collect data for the management of groundfish resources, the surveys are also a highly effective means of conducting other scientific research, from addressing basic life history questions to more advanced research such as helping to establish genetic databases for deep-sea corals. These projects often feature collaborations with other government agencies and universities, resulting in thesis dissertations, technical memoranda, and peer-reviewed papers. Here we present some results on reproductive parasitism by snailfishes of lithodid crabs.

Snailfish (family Liparidae) are probably the most broadly distributed family of marine fishes, occurring in temperate and cold ocean waters from intertidal to depths below 7,700 m. Some snailfishes of the genus *Careproctus* have the unique reproductive strategy of depositing their eggs in the branchial chambers of large lithodid crabs, probably via an ovipositor. The relationship has been described as parasitic, with effects on crabs ranging from no obvious damage to major gill compression and necrosis of half (an entire side) of the gills. Records of carcinophily consist of observations of eggs (or larvae) in crabs, but generally the fish involved are unidentified because the eggs have no distinguishing features, and snailfish are too similar in morphology to allow identification of embryos. U.S. West Coast occurrences have been reported.

We initiated a pilot study during the 2007 NWFSC groundfish trawl survey to collect data on the presence of snailfish eggs in the branchial chambers of crabs captured in the survey trawls, to identify adult snailfishes collected on the survey, to use genetic methods to match eggs to adults, and to initiate further studies of carcinophily. In 2007 we included a non-lithodid group of crabs with potential commercial value, tanner crabs of the genus *Chionoecetes*, but 807 crabs were checked for the presence of snailfish eggs and none were found. Snailfish eggs were found in four different lithodid species in 2007 and five different species in 2008. At least seven different

species of snailfish in three genera were collected during the 2007 survey, including one (*Paraliparis pectoralis*) that is rare in collections. Visual analysis of the egg masses suggests there are at least two different liparid species depositing their eggs in crabs. The most common species collected was *Careproctus melanurus*. Females collected had ovarian eggs ranging from undeveloped to 4.9 mm in size, suggesting that spawning may be protracted, even if periodic. Genetic analysis of egg masses and tissue samples taken from adult snailfish to identify which species laid the eggs was underway and results were not yet available; however, information on the relative frequency of occurrence of parasitism was presented. This work will both help clarify the natural history of two groups of species distributed worldwide: snailfishes and lithodid crabs, and, we hope, lead to clarification of the evolution of this unique behavior.

A summary of acoustic tagging programs for migratory and resident Chinook salmon in Puget Sound

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Like many other stocks throughout the Pacific Northwest, Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) have now declined to the point that they are listed as threatened under the Endangered Species Act. An increased understanding of their residence time, origins, migration pathways, predator/prey interactions, and habitat use is needed to help reverse this trend. We are using acoustic telemetry to help fill this information void. Currently there are over 20 organizations deploying more than 900 tags and over 200 receivers in every Puget Sound basin, and coincident with this is an international monitoring effort (POST project) using the same technology from California to Alaska. This presentation was a summary of the Chinook portion of this collaborative effort initiated over the last 3 years and an overview of the upcoming research plans.

To date, we have focused on two types of Chinook salmon present in Puget Sound: ocean-type, which follow the traditional life-cycle model, and residents (blackmouth) that spend their entire life in Puget Sound. We hypothesized that the ocean-type fish (based on run timing and size) would rapidly exit Puget Sound. However, many were still present in the winter months following tagging. In turn, we assumed that the resident-type salmonids would have a high probability of remaining in Puget Sound. We have detected more than 75% of these fish on at least one receiver. Over 25% were detected up to a month after release; most from receivers adjacent to the capture and release locations. Five fish released around central Puget Sound were detected moving around the same area 1–5 months later. Another two fish spent 2 and 5 months,

respectively, traveling between central and south Puget Sound and were detected on all receivers in between.

All of these findings seem to indicate that Puget Sound fish are on the move. There are different scales of movement including a surprising amount of rapid short-term long distance movement. There are also movement patterns within smaller geographic areas ("movers" and "sitters"). We are planning on continuing this research and examining these fish movement patterns for correlations with tides, diel patterns, water quality, predator/prey interactions and other possible environmental predictors.

This united approach will give a clearer picture of the status of Puget Sound Chinook salmon including ocean-bound smolt and resident (blackmouth) behavior and survival in both the estuarine and nearshore environments and contribute to a greater ecosystem level of understanding. This in turn will help direct future fisheries management decisions surrounding recovery and help focus future protection and restoration efforts.

Residence time of juvenile Chinook salmon in the Columbia River estuary

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The importance of estuarine habitat to juvenile Chinook salmon (*Oncorhynchus tshawytscha*) has been documented in many estuaries of the Pacific Northwest. However, estuarine habitat use in the Columbia River, historically one of the largest producers of Chinook salmon, is underrepresented in the literature. Conventional sampling methods can indicate presence or absence, but more comprehensive techniques must be used to measure behavioral characteristics, such as residency.

A combination of passive integrated transponder (PIT) tags, PIT tag detection arrays, and acrylic paint was used to conduct a mark-recapture study in emergent marsh habitat in the Columbia River estuary. In 2006 and 2008, respectively, 574 and 864 subyearling Chinook salmon were PIT tagged. In 2006 324 subyearling Chinook salmon were marked with acrylic paint. All target (PIT-tagged and marked) fish were released within the emergent wetland habitat. Target fish were actively recaptured using seine nets. In 2008 PIT-tagged fish were also passively monitored with two PIT detection arrays. More than 400 individual target fish were recaptured during the 2 years of the study. Residence times were greater than expected, given the tidal nature of the emergent wetland. Thirty-seven percent of recaptured fish resided for 7 or more days and 5% resided for 3 weeks or longer. Active recapture of target fish using seine nets provided individual growth rate information in addition to residence time. Instantaneous growth rates of PIT-tagged fish in 2006 and 2008 were 0.67 and 0.60 mm/d, respectively.

An unexpected benefit of the study was active and passive recovery of subyearling Chinook salmon that were PIT tagged above Bonneville Dam. These fish demonstrated significant estuarine habitat use and their growth rates were analogous to growth rates of fish collected and tagged locally.

This study verifies that subyearling Chinook salmon are dependent on estuarine habitat in the Columbia River for rearing and growth. However, the availability of estuarine habitat has been greatly reduced by diking and filling of wetlands. Restoration needs to occur so that populations of Chinook salmon, like those in the ESA-listed Lower Columbia River ESU, are able to increase.

Toxic contaminants and juvenile salmonids in the lower Columbia River and estuary

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As part of the Lower Columbia Estuary Partnership's Ecosystem Monitoring Program, we measured concentrations of contaminants in the lower Columbia River and estuary (LCR&E) environment and in outmigrant juvenile salmon to evaluate the potential risks of toxics to the productivity of ESA-listed Columbia River salmon stocks. Contaminant levels were determined in juvenile Chinook salmon (*Oncorhynchus tshawytscha*), water, and sediment samples from six sites in the LCR&E from Bonneville to the estuary mouth. Salmon from upper, middle, and lower Columbia stocks were feeding and rearing in the LCR&E, and were exposed to PCBs, DDTs, polybrominated diphenyl ethers, and polycyclic aromatic hydrocarbons via their diet, with especially high concentrations of contaminants in stomach contents of fish from the Portland/Vancouver area.

Contaminant levels in bodies and stomach contents of some fish were above thresholds for effects on salmon health, such as delayed mortality, poor growth, and reduced disease resistance. Salmon from the Portland sites also showed signs of exposure to estrogenic compounds. Moreover, concentrations of copper and organophosphate pesticides in the water column were at

levels that could interfere with olfaction in salmon at some sites. Field data are being used in bioaccumulation and population models to better understand pathways of exposure for salmon, and potential impacts on stock recovery.

Pacific salmon on the brink of ocean entry: New insight from the Columbia River estuary

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Anadromous Pacific salmon spend part of their life cycle in freshwater and part in salt water. However, the specific details of how juvenile salmon make the transition from freshwater to marine environments—a time of potentially high mortality—remains poorly understood. We have been sampling juvenile salmon and the larger estuarine fish community in the lower Columbia River estuary to address this issue and characterize salmon immediately before ocean entry. We have observed variation in both juvenile salmon and the estuarine fish community, associated with variation in physical forcing. These biological changes, in turn, likely influence juvenile salmon vulnerability to predators and therefore influence predation rates. Insight provided by this study allows us to look backwards to comprehend how salmon may have functioned in the unaltered Columbia River system, but also to look forward to predict how they may respond to further changes in climate.

Evaluating ecological and economic impacts of individual quotas for the groundfish trawl fleet

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In November the Pacific Fisheries Management Council decided to implement an individual quota system for the West Coast groundfish trawl fleet. Under the individual quota system, each vessel now has dedicated access to a portion of the quota for groundfish, such as rockfish and flatfish. This is a radical departure from the traditional competitive "race to fish." The modeling work presented here investigates the ecological and economic effects of this new management regime.

I used an integrated ecosystem model of the U.S. West Coast (Atlantis) to simulate the abundance of target fish species and other biological groups. I simulated fleet dynamics for the 12 major groundfish fleets, with each fleet choosing fishing locations that maximize net revenue. Net revenue included landed value of the catch, minus the cost of quota and fixed and variable costs. I explicitly included the penalty that fishers expect if they exceed their quota. The main findings are 1) even with crude spatial resolution, under the individual quota scenario the simulated fleets show some improved targeting behavior, avoiding overfished rockfish species and aiding recovery of these stocks, and 2) the penalty fishermen expect for exceeding quota has a large effect on fleet behavior. This points to the importance of monitoring and enforcement.

Assessing institutional designs for managing water supplies across Puget Sound

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Understanding the laws, policies, and organizational structures needed to successfully implement complex habitat management activities is critical for the recovery of Pacific salmon (*Oncorhynchus* spp.) in the Northwest. This project investigated formal and informal water supply control measures that have been implemented to support salmon recovery in the Puget Sound Basin. A census of efforts to manage freshwater flows across 18 Puget Sound Water Resource Inventory Areas was provided. This information was compared against a set of social science design principles that have been presented as necessary for the successful management of common pool resources such as water and fish.

Results from the study highlight institutional designs that are associated with the effective implementation of water supply control measures and establish whether hypothesized institutional design principles explain the success of efforts to manage freshwater supplies to support salmon recovery across Puget Sound. By identifying effective institutional designs, data from this research may assist managers in developing new flow control programs to support salmon recovery. This project augments existing social science research related to salmon recovery and offers a novel application of institutional analysis and common pool resource theory to integrated water and fisheries management scenarios.

Restoration of salmon habitat in tidal wetland habitats: An example from the Grays River tributary of the lower Columbia River

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Degraded wetland systems with impaired hydraulic connections have resulted in suboptimal habitat opportunity for salmonids and other native flora and fauna in the Pacific Northwest. Reconnection of these systems to tidal fluctuations restores connectivity and material exchange between wetland and riverine or estuarine environments. We developed and tested a series of monitoring metrics designed to evaluate and compare physical and biological responses of hydraulic reconnection, then tested the metrics at various field sites. As an example, in the Grays River tidal freshwater system, we measured hydrologic changes due to removal of tide gates from diked pastureland, and determined subsequent time series of abundance and size frequency of salmonids in the restoring marshes. Dike breaching caused an immediate return of full semidiurnal tidal fluctuations to the pastureland.

We found that juvenile salmonids quickly expanded into this newly available habitat and utilized prey items presumably produced within the marshes. There was differential habitat utilization by species, with chum salmon (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) exhibiting higher abundances in restoration sites compared with Chinook salmon (*O. tshawytscha*). There was also differential use by life history stage. All chum were fry that migrated rapidly through the system. Chinook were a mixture of fry and fingerling-sized animals that were present from March to at least July. The coho population was composed of fry, fingerling, and yearling fish also present from March to at least July. Based on size and the timing of hatchery releases, we conclude most Chinook, chum, and coho salmon sampled in restored and reference sites were progeny from wild spawners. Restoration of tidal wetlands in the lower Columbia River and estuary is likely to improve overall ecosystem connectivity, reduce habitat fragmentation, and increase resilience of varied salmon stocks to anthropologic and climatic perturbations.

Improved flatfish health following remediation of a Superfund site

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Eagle Harbor in Puget Sound became a U.S. Environmental Protection Agency Superfund site in 1987 due to high sediment concentrations of polycyclic aromatic hydrocarbons (PAHs) released chronically from a nearby creosoting facility. Early studies with English sole from this site (1983–1986) demonstrated high prevalences (up to ~80%) of toxicopathic liver lesions, including neoplasms. These lesions have been strongly and consistently associated with PAH exposure in multiple field studies, and have been induced in laboratory injections of a PAH-rich fraction extracted from Eagle Harbor sediment. Further studies (1986–88) incorporated biochemical biomarkers of PAH exposure and effect, including hepatic CYP1A expression, biliary fluorescent aromatic compounds (FACs), and DNA adducts in liver.

Prior to site remediation, hepatic lesion prevalences and biomarker values in these species from Eagle Harbor were among the highest in Puget Sound. In 1993 and 1994, a primary cap of clean sediment was placed over 54 acres of the most contaminated portions of Eagle Harbor, with a secondary cap added between November 2000 and February 2002, in order to sequester PAH-contaminated sediments. Lesion prevalences and biomarker values just before capping were reduced compared to historical data, consistent with closure of the creosoting facility closure in 1988 and subsequent shore-based source controls. Data on liver lesion risk, hepatic CYP1A, and biliary FACs from fish collected immediately after and at regular intervals up to approximately 2 years after primary sediment capping were highly variable relative to precapping values. However, over the entire monitoring period (up to 142 months) since cap initiation, but particularly after approximately 3 years, there was an overall, significantly decreasing trend in risk for hepatic lesions in English sole, and for biliary FACs and hepatic DNA adducts. In particular, the risk of hepatic lesion occurrence in English sole has been consistently low (> 0.20) compared to lesion risk at cap initiation (1.0), from approximately 4 years after sediment cap placement through April 2005; results of liver lesion occurrence through May 2007 continue to show very low prevalences.

These results show that the sediment capping process has been effective in ameliorating PAH exposure and associated biological effects in resident flatfish species, and that longer term monitoring of pollutant responses in biological resources, such as resident fish, is necessary and far superior to monitoring of only sediment contaminants in order to demonstrate the efficacy of this type of contaminant remediation.

Hatchery induced life history variation in Columbia River Chinook salmon

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In teleost fish, measurement of the androgen 11-ketotestosterone, referred to as 11-KT, in blood provides a reliable physiological indicator of the initiation of male maturation (puberty). Over the past decade, we have used this endocrine tool to reveal that approximately 10–50% (depending on population and brood year) of the male fish released from several Columbia River Chinook salmon (*Oncorhynchus tshawytscha*) hatchery programs mature precociously at age 2 (commonly referred to as minijacks) rather than the more typical age 3–5 for this species. Instead of migrating to the ocean for long-term rearing and growth, minijacks remain in headwater streams or undertake a short-term migration downstream, turn around, and attempt to migrate back upstream to complete the maturation process a few months later. Rates of minijack production in wild stocks are difficult to quantify, but believed to be less than 5%.

Age of maturation in salmon is influenced by genetic, biotic, and abiotic factors, including energy stores, size, or growth rate at specific times of year. Studies in salmonids have shown that maturation for each age class is physiologically initiated approximately 10–12 months prior to spermiation, and growth rate during this period significantly influences the physiological "decision" to mature in a given year. Growth profiles of hatchery fish are not well matched to that of wild fish, suggesting that rearing practices are a key component of the altered life history pattern. Changes in the life history composition of salmon populations are undesirable in conservation and production hatcheries, potentially resulting in loss of returning anadromous adults, biased gender ratios, and negative genetic and ecological impacts on native species. Laboratory and production scale experiments aimed at more closely matching growth profiles of wild fish have met with mixed success in that growth regimes that suppress early maturity often produce smaller fish at release. Release of smaller smolts typically results in lower rates of survival to adulthood.

Future studies are aimed at reconciling the population scale trade-offs between short-term survival advantages of large phenotype at release and potential long-term survival disadvantages of genotype alterations of fish in hatchery programs.

The promise and pitfalls of using climate data in fish stock assessment

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Concurrent declines in demersal fish stock abundances and shifts in long-term average environmental conditions in the Pacific Ocean have been well documented. However, changes in abundance of fish stocks are largely attributed to fishing impacts, rather than environmental conditions. High variability around stock recruitment curves indicates that environmental or other factors—in addition to stock size—probably affect early life history survival and subsequent recruitment to fisheries. Thus management advice that ignores environmental forcing of recruitment, the effects of which are exacerbated by fishing pressure, may cause stocks to be overharvested or underharvested.

The efficacy of including environmental impacts on recruitment in management models needs to be evaluated to move single species stock assessment methods towards taking account of ecosystem considerations. Simulation testing is used to determine the statistical power of currently used stock assessment methods to correctly identify long-term decadal-scale environmental forcing of recruitment. Three alternative stock assessment methods were evaluated: 1) fit the population dynamics model treating the annual recruitments as estimable parameters and then estimate the parameters of a Beverton-Holt stock recruitment relationship using the estimates of spawning biomass and recruitment (M0), 2) apply the stock assessment including the fit of a Beverton-Holt stock recruitment relationship ignoring the environmental data and the possibility of temporal autocorrelation in recruitment (MSR), and 3) conduct the stock assessment, but integrate the environmental data (but not temporal autocorrelation in recruitment) into the assessment (MSRE). Simulation results are based on three generalized life histories: a long-lived unproductive rockfish, a moderately long-lived and productive flatfish, and a moderately long-lived and productive hake with highly variable recruitment. The ability of the stock assessment methods to balance type I and type II error rates suggests that methods M0 and MSR tend to produce lower total error rates for the rockfish and flatfish life histories; these methods are those used most commonly in practice.

In this study, the promise of integrating environmental data directly into stock assessments is outweighed by the pitfall of high type I error rates for the rockfish and flatfish life histories, suggesting that the conventional means of avoiding spurious correlation are not sufficient when using method MSRE. The method MSRE produced the lowest total error rate for the hake life history. Type II error can be minimized if catch and index data are available for at least the same period as the environmental index, in this study 50 years. The proportion of failures was highest for hake life history, with the fastest dynamics, and lowest for the rockfish life history, with the slowest dynamics.

Acoustics: An advanced remote sensing technology in fisheries surveys

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The oceans provide a virtually boundless habitat for tens of thousands of marine species ranging from microbes to phytoplankton to zooplankton and marine mammals, the highest level in the marine food chain. The dynamic distribution of the biomass or abundance of these organisms provides the spatial and temporal signatures of the ocean ecosystem and is of crucial importance to human existence. In reality, the oceans, however, are grossly undersampled. To understand the temporal and spatial variations in the distribution of these marine species, we need to sample as much ocean volume and extract as much information as possible. Conventional pump and net samplers can provide discrete information on biomass, size distribution, patchiness, and time evolution of marine animals, but these sampling methods are time consuming and inefficient. To sample the oceans more efficiently, acoustic technology has evolved significantly from the simple analog, single-channel, and single-frequency systems to the much more sophisticated digital, multi-channel, or multi-frequency systems.

With advances in acoustic techniques, the efficiency and accuracy of oceanographic biological surveys have been substantially improved. In this presentation, a review of several major advances in sonar techniques over the past few decades was given, and their applications to and impact on fisheries surveys were emphasized. Examples of the Integrated Acoustic and Trawl Survey of Pacific hake (*Merluccius productus*) were presented to demonstrate how to extract biological information (abundance and biomass) from the recorded acoustic echograms.

Ecosystem dynamics in the northern California Current: Effects on juvenile salmon

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The Fish Ecology Division's Estuarine and Ocean Ecology Program has been studying the early life history of juvenile salmon in the coastal environment of the northern California Current (NCC) for more than a decade, examining physical and biological processes underlying variations in early marine survival. This has involved an extensive field program (three or more broad-scale cruises a year) that has sampled the environmental conditions that salmon inhabit, along with the prey field and abundances of ecologically related competitors and predators. The NCC ecosystem has undergone dramatic changes during the period encompassed by our study, including several regime shifts, one of the strongest El Niños ever recorded, a strong La Niña, years with pronounced subarctic water influence, and anomalous upwelling conditions, providing a natural experiment to test the effects of the ocean on salmon marine survival.

Our analyses of the collected data have led to a better understanding of the distribution, migration routes and speeds, growth, condition, feeding, and health of juvenile salmon in the coastal marine environment. We have developed maps of preferred habitats for both Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) based on multiple physical parameters. Species and stock-specific migration behaviors have been elucidated through recovery of tagged fish and also genetic techniques. Growth variability has been examined through scale and otolith analysis. Feeding ecology has been studied through direct diet analysis, parasites, and the use of stable isotopes. The health of juvenile salmon has been studied through examination of pathogen and parasite infections. Concurrent with our salmon sampling, we have examined the prey field of these juveniles at higher spatial and temporal scales to monitor changes in the ocean environment that may affect salmon. We also monitored the abundance and feeding habits of potential piscine and avian predators and examined their spatial overlap with juvenile salmon. A related component has examined the abundance and ecology of several forage fishes that serve as prey for juvenile and adult salmon.

In recent years, we have incorporated our field observations into biophysical models of the environment and food web in the NCC, using these models to test hypotheses about abiotic and biotic control on salmon survival. We have been using these models to examine the effects of climate and ecosystem change on salmon, providing managers with some leading indicators of potential recruitment trends in salmon populations.

The enigma of *Vibrio parahaemolyticus* outbreaks in the Pacific Northwest

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Members of the genus *Vibrio* are ubiquitous in the marine environment, especially in coastal waters. These bacteria accumulate in shellfish such as oysters through filter feeding and are the leading cause of seafood-related bacterial infections reported in the United States. *Vibrio parahaemolyticus* is commonly acquired by consumption of undercooked or raw shellfish and is responsible for the majority of these infections, primarily manifested as a self-limiting gastroenteritis.

In the past decade, there has been a significant increase in *V. parahaemolyticus*-related gastroenteritis from the consumption of raw oysters harvested in the Pacific Northwest, possibly attributable to increases in water temperature. Such illnesses and outbreaks pose a threat to public health and result in severe economic losses to the shellfish growers. Increases in *Vibrio* populations due to changes in climatic conditions have been previously reported, but the ecology of these bacteria and their interactions with the aquatic environment are not clearly understood.

The Washington State Department of Health currently monitors oysters from May to September of each year from selected growing areas that have previously been associated with *V. parahaemolyticus*-related illness with a mandate to close harvesting if concentrations of potentially pathogenic (tdh+) *V. parahaemolyticus* exceed action levels of 50 bacteria per gram of oyster meat. Rarely, however, have these levels been reached for the past few years, and there has been little or no correlation between the concentrations of tdh+ *V. parahaemolyticus* in oysters harvested from growing areas associated with illnesses.

We are presently investigating the influence of environmental variables on concentrations of potentially pathogenic and avirulent strains of *V. parahaemolyticus* in oysters as well as in water and plankton, focusing on harvest areas with historically higher incidences of the bacteria. In addition we are examining the association of *V. parahaemolyticus* with co-isolated phytoplankton and zooplankton species. Through this work, we hope to gain a better understanding of environmental conditions that promote proliferation of these bacteria, which may assist in the improvement of risk assessment strategies and mitigation tools to prevent disease outbreaks.

Acoustic tracking of hatchery-reared lingcod in Puget Sound

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Lingcod (*Ophiodon elongatus*) are being developed as a model species to test hypotheses about stock enhancement. This research addresses stock enhancement issues concerning egg collection, rearing, and release strategies, and will expand in the future to include assessments of ecological interactions and genetic impacts. This work may also provide insight into the behavior and ecology of wild juveniles, which can be elusive and for which minimal field data exist. In 2008 eggs were collected from the wild and reared at the Manchester Research Station. Forty-eight telemetry-tagged, hatchery-reared subyearlings were released into South Puget Sound in November 2008 and are being tracked with an array of stationary acoustic receivers and a mobile boat-mounted receiver.

This talk presented some preliminary data from the mobile tracking work that aims to document movement, habitat associations, and possible eventual recruitment to adult habitat. This project is a collaboration with the Washington Department of Fish and Wildlife, the Northwest Indian Fisheries Commission, the Washington SCUBA Alliance, and the Puget Sound Recreational Fishery Enhancement Committee.

Early marine survival and behavior of steelhead (*Oncorhynchus mykiss*) smolts through Hood Canal and the Strait of Juan de Fuca

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The depressed status of Puget Sound steelhead trout (*Oncorhynchus mykiss*) populations contrasts with the healthier condition of those along the Washington Coast and suggests that substantial smolt mortality occurs during the migration through Puget Sound to the Pacific Ocean. Acoustic telemetry transmitters and stationary receivers were used to investigate survival, migration timing, and migratory behavior of 159 steelhead smolts in 2006 and 187 smolts in 2007 from four Hood Canal (part of Puget Sound) streams and one stream flowing into the Strait of Juan de Fuca.

Estimated population-specific survival rates for wild and hatchery smolts from river mouths to the northern end of Hood Canal (28.1 to 75.4 km) ranged from 67% to 85% in 2006 and from 64% to 84% in 2007. Survival was much lower from the north end of Hood Canal to the Strait of Juan de Fuca (135 km) in 2006 (23% to 49%), and could not be reliably measured in 2007. Travel rates through Hood Canal (8–10 km/day) were significantly lower than those estimated as the fish migrated through northern Puget Sound and the Strait of Juan de Fuca (26–28 km/day), while the mortality rates per unit distance traveled were very similar in the two segments. The high daily mortality rates estimated during the early marine phase of the steelhead life cycle (2.7%/day) suggest that mortality rates decrease substantially after steelhead enter the Pacific Ocean.

Pesticides as a limiting factor for salmon recovery in the western United States

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Pesticides pose a complex threat to the biological integrity of aquatic ecosystems. In the western United States, widespread pesticide use has contaminated surface waters that provide habitat for endangered Pacific salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*). These keystone species depend on the productivity of rivers, lakes, and estuaries to provide food for juvenile growth, a key determinant of subsequent marine survival. Because pesticides can be toxic to many nontarget taxa (e.g., primary producers and macroinvertebrates), they can have adverse but still poorly understood impacts on salmon populations via indirect trophic cascades. In addition to food web effects, this presentation reviewed recent NWFSC research on the toxicity of pesticide mixtures, interactions between pesticides and nonchemical stressors (e.g., stream temperatures), and links between the health of individual salmon and the productivity of wild populations.

Super crunching multispecies monitoring data

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Multivariate autoregressive (MAR) modeling is a form of multivariate analysis that uses time series data from multiple species along with physical factors to infer interspecies interactions, the dominant environmental drivers, and the system stability and resilience. MAR modeling is well-grounded on theory concerning population and community dynamics. Using estimated MAR models, comparative properties of communities, such as resistance to disturbance, resilience, and return time after disturbance are easily calculated in terms of the stability properties of the matrix of species interaction strengths.

This framework has been used successfully to understand the dynamics of various freshwater plankton communities. We are extending this statistical framework in order to apply it to the analysis of marine community data and to estimate the impacts of physical, biological, and anthropogenic drivers on marine ecosystems. I introduced the ecosystem modeling tools we have developed based on MAR and provided snapshots of a variety of ecosystem analyses where we are using these tools.

Effects of temperature change on demersal fishes in the California Current: A bioenergetics approach

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Diverse fish assemblages such as West Coast groundfish should feature a wide range of biological and ecological responses to temperature change. This is borne out by bioenergetics modeling. When temperatures were varied around historic annual means, three groundfish species—yelloweye rockfish (*Sebastes ruberrimus*), sablefish (*Anoplopoma fimbria*), and spiny dogfish (*Squalus acanthias*)—responded with different intensities across several key variables (age-1 mass, age at 50% maturity, and prey consumption).

Translating such results to a field setting is a challenge. Temperature change may directly affect fish bioenergetics, cause range shifts related to behavioral thermoregulation, or produce complex ecological interactions, all of which can affect fish populations and influence management decisions. Future research priorities are to quantify temperature sensitivity among species and anticipate temperature-mediated changes in populations and diverse communities.

Rebuilding depleted West Coast groundfish species: Management actions and early results

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The Sustainable Fisheries Act of 1996 established a new mandate for NOAA Fisheries Service to identify and rebuild depleted fish stocks under its jurisdiction. Since 1996 seven rockfish and two other groundfish stocks that inhabit waters off Washington, Oregon, and California have been declared overfished. In response to these declarations, a variety of measures have been implemented in an effort to rebuild the depleted stocks to target biomass levels. These responses have included dramatic reductions in optimum yields, new restrictions on gear usage, designation of closed areas, and the development of a comprehensive, scientific observer program. The two nonrockfish species that were listed as overfished have since been declared rebuilt and two of the rockfish stocks are expected to reach target biomass levels within the next few years. For some rockfish species, however, rebuilding is expected to take more than 60 years. Assessments were conducted during 2007 for all of the depleted rockfish species, as well as several others. The progress toward rebuilding will be evaluated through examination of biomass trends reported in these assessments.

Known unknowns now known: The fish heart as a target for the long-term impacts of oil spills

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Studies following the 1989 Exxon Valdez oil spill in Prince William Sound showed that the early life history stages of fish are highly sensitive to lingering trace crude oil contamination. Pink salmon (*Oncorhynchus gorbuscha*) exposed to oiled gravel as embryos showed significantly reduced juvenile to adult marine survival in tagging studies. Using zebrafish (*Danio rerio*), we have cracked into the black box of the mechanisms underlying this delayed mortality. Studies with weathered crude oil and the most abundant types of crude oil-derived polycyclic aromatic hydrocarbons (PAHs) showed that tricyclic PAHs acutely disrupt cardiac function in developing fish embryos. The well-known links between cardiac form and function during development and the relationship between the shape of the fish heart, cardiac output, and maximum swimming speed suggest that early disruption of heart function will have long-lasting physiological impacts on oil-exposed fish embryos. Consistent with this, zebrafish exposed to sublethal levels of crude oil as embryos were found to have reduced swimming performance as adults in spite of identical condition factors.

These findings suggest a hypothetical basis for the development of biomarkers relating to cardiac performance, such as cardiac natriuretic peptides secreted in response to hemodynamic stress that, in conjunction with biomarkers of exposure such as cytochrome P4501A or levels of fluorescent aromatic compounds in bile, may provide a more sensitive and efficient means for assessing oil spill impacts on fisheries resources.

Using PIT tag technologies to investigate adult salmonid straying in the lower Columbia River

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Accurate estimates of adult salmonid survival rates are critical for meeting hydrosystem performance standards established by NOAA Fisheries Service biological opinions. Straying and adult fallback rates are key components in adjusting adult survival estimates. Previous methods to estimate straying have been limited. Fish Ecology Division researchers proposed to evaluate the feasibility of using passive integrated transponder tag (PIT tag) systems to estimate straying in large tributaries.

A prototype PIT tag system was installed near McDonald Ferry on the John Day River in September 2007. This site is located in the lower reach of the river (around RM 20) and is below all of the major spawning tributaries. The detection system consists of six antennas installed as two arrays into the thalweg portion of the river. By installing two antenna arrays, researchers can infer travel direction and increase the overall tag detection efficiency of the PIT tag system.

Since 27 September 2007, the detection system has been operating continuously to monitor migrating PIT-tagged adult salmonids. Through December 2008, we have detected 227 PIT-tagged adult salmonids and 37 juveniles. The majority of the adults (≈85%) have been steelhead (*Oncorhynchus mykiss*). Steelhead appear to be actively migrating over longer periods of time and at different times than had previously been thought while the native spring Chinook salmon (*O. tshawytscha*) migration pattern has followed the expected springtime-only migration pattern. We will continue to monitor the river in 2009 and 2010 to see if the first year's patterns were unique or reflect the normal migration patterns for this river.

Of the 196 steelhead detected, 71 were straying fish that originated outside of the John Day River basin. Most (56) of the straying steelhead were fish transported from Lower Granite Dam. These were detected in the fish ladders at Bonneville Dam between July 2007 and October 2008 when approximately 3,300 other similarly transported fish were also detected. This would suggest an overall straying rate of approximately 2%; however, certain release locations within this larger group yielded higher rates.

We know the number of tagged fish that the PIT tag system has detected, but we do not know how many it has not detected. Therefore, in September 2008, we started an evaluation to determine the detection efficiency of the PIT tag system using test fish double-tagged with PIT and radio tags. We set up two radiotelemetry antenna arrays below and two above the PIT tag antennas to monitor the double-tagged fish. Due to a strong native run and permit complications, we were able to double tag only seven fish (four hatchery and three wild fish). The PIT tag system has detected all five double-tagged steelhead that have passed the antennas. The other two fish are still below the PIT tag antennas. We plan to start tagging more fish in September 2009.

Poster Presentations

Migration timing, growth, and estimated parr-to-smolt survival rates of wild Snake River spring-summer Chinook salmon from the Salmon River basin, Idaho, to the lower Snake River

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Survival, growth, and juvenile migration timing are key life history traits for at-risk salmon populations. To estimate these traits in threatened wild Snake River spring-summer Chinook salmon (*Oncorhynchus tshawytscha*), we tagged these fish as parr in 3 to 17 natal streams from 1988 to 2008. We injected passive integrated transponder (PIT) tags into parr collected from streams within the Salmon River basin in Idaho. Each spring, after the previous summer's tagging, fish were detected as smolts in the juvenile fish bypass systems of lower Snake River dams.

Estimated parr-to-smolt survival to Lower Granite Dam (excluding migration years 1989–1992) ranged from 3 to 48% for individual populations and from 8 to 25% (yearly average 16%) for all streams combined. From 1998 to 2004, estimated parr-to-smolt survival declined from 25 to 8%, then from 2005 to 2008 survival increased from 8 to 21%, due in part to parr density-dependent effects. Overall annual average growth rates from tagging to detection at Little Goose Dam ranged from 35.1 to 44.5 mm from 2001 to 2008, with significant differences in growth among sites and years. Growth of individuals was positively related to elapsed time between tagging and recapture and negatively related to length at tagging. Annual migration timing distributions for fish populations from the different streams varied highly within and between years. From 1989 to 2008, timing of the 10th to 90th percentile passing Lower Granite Dam ranged from 22 to 55 days for the combined wild populations (average 39 days). Median passage date was negatively related to autumn temperature, spring temperature, and March river flow and was positively related to elevation of the tagging site.

Baseline data generated by this project provide a foundation for understanding the biocomplexity of these populations, an understanding critical to effective recovery efforts for these threatened wild fish stocks.

Spatial ecosystem modeling of the upper Gulf of California using Atlantis

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A spatially explicit biogeochemical food web model of the upper Gulf of California (Sea of Cortez) is developed using the Atlantis modeling framework. The purpose of the study is to simulate and test various ecosystem-based management (EBM) strategies for the upper gulf to determine likely impacts on artisanal fisheries and conservation of marine resources, including rare and endemic species. Parameterization of the model in this data-poor region has relied on numerous field studies directed to provide original data for the Atlantis model. Efforts include trawl sampling, reef diving transects, stomach content analysis, community interviews, port-level sampling and log book analysis, and reconstruction of biomass trends from local ecological knowledge interpreted using a fuzzy logic approach.

A new spatial biomass allocation algorithm based on substrate, habitat affinities, and other factors increases the applicability of biomass data. A novel maximum-likelihood method is used to interpret stomach content data for the diet matrix. Modifications have been made to Atlantis to improve representation of the area's ecology and take advantage of specialized data. Recommendations from this project will influence regional EBM plans and species-specific management plans to be adopted by Mexico fishery authorities in the 2010–2012 time frame.

NMFS and ecoinformatics: Using technology and databases to help restore endangered and threatened salmon populations

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The evolution of computer science and database technology has impacted fisheries science in countless ways. The discipline of ecoinformatics—the management of biological and environmental information with a focus on both human and computer elements—is quickly becoming an essential tool within the NMFS organization, and it too continues to evolve.

At the Northwest Fisheries Science Center, we have developed several such tools to aid technical recovery teams (TRT) in the management and production of data critical to salmon Endangered Species Act listing decisions. The Salmon Population Summary (SPS) database and the Salmon Population Analyzer (SPAZ) statistical program were created to aid in the production of regular status review reports. SPS is a database system that stores salmon abundance, wild fraction, harvest numbers, and age structure data summarized at the evolutionarily significant unit and population level across the Northwest Region. SPAZ is a statistical package that utilizes the data generated in SPS to produce population trend data that then feeds directly into the listing and de-listing decisions under the ESA.

In the recent past, each TRT chair had different methods and practices when dealing with his or her own salmon data. This resulted in a very tedious and labor intensive endeavor when it came to generating the needed salmon population summaries and trends for a status review. Moving forward, it is our intent with both SPS and SPAZ to allow those tasked with the job of restoring endangered and threatened salmon species the ease and flexibility to manage their own data on a central system. SPS and SPAZ will demonstrate how a large agency in charge of managing data over a very large spatial scale can benefit from the tools created within ecoinformatics.

Diel patterns of behavior in sixgill sharks, spiny dogfish, and ratfish: Patterns, causes, and ecosystem consequences

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Understanding life histories of apex predators is crucial for understanding how marine ecosystems respond to human perturbations as well as for effectively conducting ecosystem-based management. Even so, we lack basic knowledge of many large predatory fishes. In Puget Sound, we are investigating diel vertical movement patterns of sixgill sharks (*Hexanchus griseus*), the largest resident predatory fish in Puget Sound, to determine what drives changes in their behavior.

We acoustically tagged 39 sixgill sharks with pressure sensor acoustic transmitters and monitored their movement patterns via passive and active acoustic tracking methods in Puget Sound, Washington. Sixgill sharks show very consistent diel patterns of vertical movement where they inhabit shallower waters at night and move into deeper waters during the day. This pattern is consistent between both sexes and across the entire size range of individuals collected (100–300 cm total length). Seasonally, sixgill sharks inhabit deeper waters in the fall and winter, while moving to shallower waters during the spring and summer. The sixgill shark also shows much more activity at night and during the summer. In addition, pairs of sharks tracked simultaneously made synchronous ascents and descents throughout entire 24-hour tracking periods.

These behaviors are consistent with the hypothesis that sixgill sharks are responding to similar stimuli and that they are using these periods of increased activity to forage for prey. Potential prey of sixgill sharks that make similar diel patterns of vertical movement include spotted ratfish (*Hydrolagus colliei*), Pacific hake (*Merluccius productus*) and Dungeness crabs (*Cancer magister*). We have begun to monitor the movements of spotted ratfish and spiny dogfish (*Squalus acanthias*) in the same waters as sixgill sharks to investigate interactions within the community.

Community and genetic analyses of macroparasites from Pacific sardine (*Sardinops sagax*) caught in the California Current system

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Tagging studies of Pacific sardine (*Sardinops sagax*) during the peak of their fishery in the 1930s and 1940s suggested that larger individuals migrated north to feedings grounds off the Columbia River and into Canadian waters after spawning off southern California in April. These large sardines remained in the Pacific Northwest until the onset of winter storms before they migrated back to southern California to overwinter.

To assess the current behavior and potential population structure of Pacific sardine within the California Current system, we are examining the community structure of macroparasites, which are acquired through trophic interactions. Approximately 2,200 sardines were collected from 2005 through 2007 between lat 50° to 32°N, and long 120° to 125°W. From approximately 1,000 sardines examined to date, we have identified 5 parasite species as potential biological tags. The trematodes *Lecithaster gibbosus* and *Pseudopentagramma petrovi* were common only off Vancouver Island, while the nematode *Anisakis* spp. was common from Vancouver Island to northern California. The trematodes *Parahemiurus merus* and *Myosaccium ecaude* were found throughout the study area but were most prevalent off southern California.

Recently, as a complementary approach to the macroparasite community analysis, a population genetic analysis of the mitochondrial gene COX2 in *Anisakis* spp. was initiated to assess whether the genetic structure of *Anisakis* spp. can provide insight into the population structure of sardines. Fifty-five unique haplotypes were observed in 66 individual nematodes. Overall nucleotide diversity was 4.7%. Identical nematode haplotypes were observed off the Columbia River (n = 4), the Columbia River and Willapa Bay, Washington (n = 2), Newport, Oregon (n = 2), and off California at Point Delgada and San Nicolas Island (n = 2). More individual nematodes will be examined from off Vancouver Island and southern California.

With four different macroparasite communities currently identified, our data suggest that Pacific sardines are not migrating throughout the entire study region. Thus the historical paradigm of one sardine population migrating between southern California to southern British Columbia may no longer be accurate.

Sound toxins: A harmful algal bloom and *Vibrio* monitoring program for Puget Sound

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Harmful algal bloom (HAB) species and *Vibrio* outbreaks are becoming increasingly numerous and widespread throughout Puget Sound. Every year since the 1950s, shellfish harvesting has been halted in this region as a result of concentrations of paralytic shellfish toxins produced by the dinoflagellate *Alexandrium*. The first documented closure of shellfish harvesting due to high concentrations of the neurotoxin domoic acid, produced by the diatom *Pseudo-nitzschia*, occurred in Puget Sound in September 2003. Disease outbreaks and shellfish closures due to the bacterium *Vibrio parahaemolyticus* occurred initially in 1997–1998 and again in 2006–2007. The flagellate *Heterosigma akashiwo* has caused severe economic losses to fish farming operations in Puget Sound over the last decade. Several species of *Dinophysis*, a known toxin producer, are present in Puget Sound and yet there is no formal testing program for its associated toxins in Washington State.

Attaining a predictive capability for these harmful events and identifying steps to mitigate their effects depends on quickly gaining an understanding of the conditions that promote their occurrence. To this end, the Partnership for Enhanced Monitoring of HABs and *Vibrio* in Puget Sound (SoundToxins) was established in the fall of 2007 as a regional forum for collaboration and cooperation among federal, state, and local agencies, tribes, marine resource-based businesses, public interest groups, and academic institutions to manage the prediction of and response to HAB species and *Vibrio* in Puget Sound using a practical blend of emerging and proven technologies.

Data from the past year's coastal monitoring efforts at 10 sites in Puget Sound and the Environmental Protection Agency's Ocean Survey Vessel *Bold* cruise showed measurable numbers of *Alexandrium*, *Pseudo-nitzschia*, and *Dinophysis* at several locations in Puget Sound. The ultimate goal of SoundToxins is to provide sufficient warning of HAB and *Vibrio* events to enable early or selective harvesting of shellfish, thereby minimizing risks to both human and fish health and reducing economic loss to Puget Sound fisheries.

Plasma IGF-I level as an index of growth: Interannual and geographic variation in the growth of salmon smolts at sea

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Insulin-like growth factor-I (IGF-I) is one of the primary endocrine mediators of cell division and growth. Several experiments have been conducted to validate this premise in juvenile coho salmon (*Oncorhynchus kisutch*) and a relatively robust relation between plasma IGF-I and individual growth rate has been found (r^2 = 0.45–0.70). Subsequently, blood samples have been obtained from juvenile salmon captured in a large-scale oceanographic survey of salmon distribution and abundance off the northwest coast of the United States (Oregon and Washington) in the Pacific Ocean (2000–2007). Significant interannual differences in mean plasma IGF-I level of coho salmon captured in June have been found. Moreover, these differences in plasma IGF-I level relate directly and significantly to year-class survival in these fish. Thus plasma IGF-I levels predict oceanic survival rates of coho salmon.

In 2007 a more extensive survey was conducted and plasma IGF-I levels were measured in coho salmon captured from the Oregon Coast (lat 45°N) to Southeast Alaska (lat 56°N). Significant regional differences in IGF-I level were found, with higher levels found in more northerly waters. These data support the paradigm that juvenile salmon migrate north to take advantage of better growth conditions at northern latitudes, such as more abundant or higher quality food resources. Overall, plasma IGF-I levels appear to provide an accurate index of growth rate of salmon juveniles at sea and these growth estimates allow one to make useful ecological inferences.

Science to support complex decisions: U.S. West Coast groundfish fisheries

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The management of U.S. West Coast groundfish fisheries is increasingly complex, and spatial analysis plays an important role in the science which supports management decisions. A variety of data sources are used in the decision making process and the spatial component of these data can enhance understanding of both the fishery and fish resources. The major types of data in this process are 1) fishery independent resource surveys, which are used to determine fish population, abundance and distribution; 2) fishery dependent data, which are reported by the fishery, fish processors, or through observation of the fishery; 3) environmental factors, which can influence fish populations and their distribution; and 4) regulatory, management, and jurisdictional boundaries, which are the final derived product of the decision making process and also play a significant role in future spatial review of fishery activities and fish resources. The ability to spatially overlay, query, and extract information related to fish resources, fishing activities, fish landed in ports, fish discarded at sea, environmental factors, and regulatory measures is critical to expanding our knowledge of dynamics in the groundfish fisheries and to provide the best available science for management.

Pilot work using a codend video camera for improved ground truthing of fisheries acoustic data

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One of the difficulties in fisheries acoustic surveys is determining what organism or combination of organisms is causing the echo return at a given depth in the water column. Assignment and proportioning of areas of backscatter to particular species influences the biomass estimate of the species targeted by the survey. Therefore, accurate ground truthing of the acoustic signal is crucial.

Typically, ground truthing consists of using midwater trawls with a target depth corresponding to the area of interest. However, this can be problematic because it may not provide information about the depth at which the species were caught and most likely will miss small scatters which could be important contributors to the echo intensity. To address this concern we carried out pilot work using a video camera mounted in the codend of an open midwater trawl. For each of our eight successful test tows conducted during the 2008 hake intervessel calibration cruise, we were able to examine several different backscatter layers in the water column. The recorded video tapes were analyzed and the percent and size composition of the species in these different layers was determined. Additionally, we conducted closed codend tows with no camera at the same location, which enabled us to calculate and compare backscatter measurements between the two tow types. We conclude that this method appears to provide improved ground truth information and we plan to integrate this technology into our future acoustic surveys.

Spatial and temporal variations in albacore habitat in the northeast Pacific using remotely sensed environmental data

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Albacore tuna (*Thunnus alalunga*) occur through much of the temperate waters of the North Pacific and undergo zonal feeding migrations across the entire basin. Oceanic habitat preferences and timing of immigration and emigration into the eastern North Pacific have not been studied in detail.

An hypothesis of interest is related to the role of the North Pacific Transition Zone frontal structure as an oceanographic mechanism determining the route and rate of albacore trans-Pacific migration. We used albacore logbook catch per unit of effort (CPUE) data for 1999 through 2004 stratified by month, latitude, and longitude (33,652 records) along with satellite-derived environmental variables (Reynolds SST, SeaWIFS SSChl, AVISO SSH, and ERS- or QSCAT-derived wind stress curl). CPUE was mapped for the main fishing season (May through October), overlaid on environmental maps, and pixel-by-pixel environmental records were extracted for each catch location where fishing occurred using both positive and zero sets. The optimum range (mean and variance) of each variable was estimated based on catch and CPUE was related to all environmental variables using generalized additive models (GAM) modeling by month and year or for the whole data set combined and also east and west of long 130°W.

Finally, we plotted a binary prediction map of distributional range of this species based on optimal habitat for each month and year.

Catch varied significantly between years and all four environmental factors were related to the distribution of albacore in this region.

Analysis of Pacific sardine stocks derived from number of vertebrae

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It is critical to successful management of the Oregon and Washington Pacific sardine (*Sardinops sagax*) fisheries to know if fish caught in the Pacific Northwest are a discrete population. Previous research has hypothesized that the Pacific sardine has three subpopulations based off California. One method used for defining Pacific sardine populations is vertebral counts. It is accepted that many species of fish from warmer waters have lower average number of vertebrae than fish of the same species from colder waters. This study used this assumption to examine vertebral counts of Pacific sardine captured from San Pedro, California, to Willapa Bay, Washington. We found no significant difference in vertebral counts between any of the samples ($P > 0.01$).

Construction of a habitat map for Heceta Bank, Oregon, for use in estimates of groundfish assemblages on the bank

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Heceta Bank, offshore Oregon, is one of the largest rocky banks along the U.S. West Coast and contains a diverse array of habitats supporting numerous species of commercially important groundfish, including a diverse assemblage of rockfishes (*Sebastes* spp.). In 1998 we collected high-resolution bathymetry and backscatter imagery of the bank using a Simrad EM 300 multibeam echo sounder, and returned in 2000 and 2001 to conduct strip transect video surveys of habitat, fish, and invertebrates using the remotely operated vehicle (ROV) ROPOS. These in situ data have been analyzed for fish habitat relationships.

One of the critical elements of this project was to create the first comprehensive lithological habitat map of the bank. Polygons of uniform habitat were constructed by analyzing the image data (bathymetry, backscatter, topographic position index, and slope) and reconciling with the video data. Habitat areas identified include high-relief ridge sediment complex, heavily eroded ridge complex, pinnacle, boulder/cobble, and unconsolidated sediment (mud and sand).

This map, combined with the fish observations made in the ROV video, may be used as a tool to extrapolate groundfish abundances for the entire bank and adjacent areas surveyed by dive transects.

Annual residency patterns of Southern Resident killer whales in the inland waters of Washington and British Columbia

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Southern Resident killer whales are listed as endangered in both the United States and Canada. Both countries have recognized the importance of the transboundary inland waters of the Puget Sound and Georgia Basin as core summer habitat for these whales by designating this area as critical habitat. However, these whales, comprised of three pods or family groups, only spend a portion of their time here, ranging to the outer coast throughout the year. While summer occurrence patterns have been studied, it is important to assess year-round patterns of occurrence and how these patterns vary annually, seasonally, and by pod.

Sightings were compiled from January 2003 to December 2007. This time period was chosen due to a marked increase in year-round sighting effort as compared to previous years. Sightings from a wide variety of sources including the public, commercial whale watch operators, and researchers were reported to Orca Network. Sightings were compiled by pod, and those with uncertain pod identifications were compiled separately (adding these sightings did not alter patterns of residency). For a given day, the whales' location was assigned to one of four areas: Puget Sound, San Juan Islands, Eastern Strait of Juan de Fuca, and the Fraser River/Gulf Islands. This location represents the area in which the whales spent the majority of their time on that day based on sighting reports. Additionally, the amount of time between sightings was calculated to begin to assess potential range when not in the inland waters.

For the 5-year period, southern residents were reported in the inland waters on average 46% of days, ranging from 39% in 2006 to 56% in 2003. There has been a decline in the number of days spent in the inland waters, but there is a substantial amount of variability between years. Sightings are relatively rare from January to March (0–20% of days/month), increasing in April and May, peaking in June (75–100% of days/month), and then declining through December to levels slightly higher than those in January. Occurrence also varied between pods. J pod occurred more often in inland waters than K and L pods (40.5%, 20%, and 22% respectively). J pod was most commonly present from May-July (>70%) compared to K and L pods, which were most commonly present from June to September (>50% and >60%, respectively).

Sightings were most common in the San Juan Islands, representing 29–41% of all sightings in inland waters. While increased effort may have positively biased these numbers, they are consistent with previous summer habitat studies. Sightings in Puget Sound only occurred from October to January, while sightings occurred in the other three areas throughout the year.

Time periods between sightings for all three pods were shortest during the summer months, averaging 1–3 days and increasing to upwards of 90 days from January to April for K and L pods. In all months J pod had shorter absences from the inland waters, suggesting a smaller coastal range than K and L pods.

The timing and location of spawning for the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera* off the Oregon coast

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Our 10-year time series (1996–2005) of biweekly sampling of *Euphausia pacifica* and *Thysanoessa spinifera* off Newport, Oregon, shows peaks in euphausiids eggs occurring from late February through early November with a great deal of interannual and cross shelf variability. Euphausiid egg density is poorly correlated with chlorophyll concentrations and surface temperature. We gain greater insight into the phenology of euphausiid spawning through the study of adult euphausiid densities and continuous data sets (temperature and currents from a mooring on our transect line, wind data, and the Bakun upwelling index) from the area.

Potential role of nonretinal, nonpineal opsins in modulating effects of light on pituitary hormone secretion in Pacific salmon (*Oncorhynchus* spp.)

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In vertebrates, seasonal reproduction is regulated by endocrine responses to day length and in some cases light quality. Most mechanistic studies have focused on light perception by the retina or pineal gland, yet in some nonmammalian species, photoperiodic cycles of gonadal development persist even after removal of the eyes and pineal gland. Photoreceptive proteins, or opsins, are present in deep brain tissue in addition to the retina and pineal gland, and have been localized near gonadotropin-releasing hormone neurons in birds. However, little is known about the mechanisms whereby light influences the hypothalamus-pituitary-gonad (H-P-G) axis.

To better understand the influence of light on salmon reproduction, we are investigating the physiological link between nonretinal and nonpineal light perception and the release of reproductive hormones in the H-P-G axis. We hypothesize that light influences pituitary hormone release via opsins present in the hypothalamus or pituitary or both. As a first step to test this hypothesis, we examined the expression of mRNA for the five salmon visual opsins by reverse transcription polymerase chain reaction (RT-PCR) of total RNA from the eye, whole brain, and pituitary gland of sockeye salmon (*Oncorhynchus nerka*).

In the pituitary, four of the five salmon visual opsins were detected and mRNA for a yellow-green light receptor (rhodopsin-1) and ultraviolet light receptor (short-wave sensitive-1) was present at quantifiable levels. To determine whether the sensitivity of the pituitary to different qualities of light changes during sexual maturation, the abundance of opsins in pituitaries collected between March and October leading up to spawning was assessed by quantitative real-time PCR. While the rhodopsin-1 mRNA abundance remains stable, the level of shortwave sensitive-1 mRNA is elevated just prior to and during spawning. These data are the first report of multiple opsins detected in the pituitary gland at abundances that are regulated differently with a shift in life history stage.

We then tested the direct effects of light on the pituitary gland by exposing isolated coho salmon (*Oncorhynchus kisutch*) pituitaries to full spectrum light or complete darkness in a medium containing isobutylmethylxanthine to inhibit phosphodiesterase. Levels of the intracellular messenger cyclic guanosine monophosphate (cGMP) were measured since opsins are G-protein coupled receptors that can couple to phosophodiesterase or guanylyl cyclase. Levels of the

gonadotropins secreted into the media were also assessed. Pituitaries exposed to light had significantly higher levels of cGMP than those maintained in darkness. However, no consistent effect of light on gonadotropin release was observed.

Future experiments will localize opsins to specific cell types in the pituitary so that assessments of light on secretion of specific pituitary hormones can be examined.

Benthic marine debris sampled during the 2007 and 2008 Northwest Fisheries Science Center's West Coast groundfish trawl surveys

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We investigated the composition and abundance of benthic marine debris collected during the 2007 and 2008 West Coast groundfish trawl surveys. The NWFSC's Fishery Resource Analysis and Monitoring Division conducted the surveys along the West Coast (55–1,280 m) from May to October of both years. Four chartered West Coast trawlers participated in the survey with two passes down the coast, from north to south. The survey area was partitioned into approximately 12,000 equal-area cells (1.5 by 2.0 nmi) with each vessel assigned an annual subset of 188 randomly selected cells to sample. An Aberdeen-style net with a small mesh (1.5-inch stretch) liner in the codend was used for sampling. Target tow duration was 15 minutes.

Marine debris was recorded in 200 tows in 2007 and 269 tows in 2008. Total debris recorded from all tows weighed 5,318 kg (range 0.01–2,000 kg/tow). The largest item taken during the survey was a fishing net (2,000 kg) retrieved by the fishing vessel *Ms. Julie* off California. Debris was subdivided into broad categories (plastic, metal, fabric, glass, rubber, Styrofoam, and unsorted), and further categorized as military or fishing debris as needed. Plastic and metal debris were encountered most frequently with 484 kg of plastic taken in 218 tows and 984 kg of metal taken in 208 tows. Fabric (346 kg) was present in 146 tows while glass debris (100 kg) was present in 123 tows. The unsorted category included items that spanned multiple categories, were found in sealed trash bags, or were too big to sort. This category was the largest by weight at 3,176 kg and occurred in 76 tows. Preliminary results indicate that benthic marine debris is more frequently encountered in the southern portion of the survey, occurring in 65% of the southernmost tows versus 25% overall.

Impacts of reduced stream flow on growth and movement of juvenile steelhead in an artificial stream channel

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While stream flow and temperature are widely recognized as important determinants of habitat suitability for salmonids in freshwater systems, the degree of importance varies with species and life stage. Furthermore, while flow and temperature have been strongly implicated in viability, productivity, and distribution for salmonid populations, it is difficult to discern negative impacts caused by changes in stream flow from those caused by changes in temperature because the two are often closely correlated. A better understanding of how flow and temperature affect juvenile salmonids would benefit fisheries, land use, and water management practices.

We examined the acute impacts of flow and temperature on growth and movement in steelhead fry (*Oncorhynchus mykiss*). We experimentally reduced stream flow and increased water temperature using the artificial stream system at the NWFSC's Manchester Research Station. Juveniles were stocked in four treatment sections and subjected to changes in water temperature and flow levels following an acclimation period. Treatment sections consisted of flow reduction only, temperature increase only, simultaneous flow reduction and temperature elevation, and a control. Depth and discharge under low flow conditions averaged 7 cm (±1.78) and 3 cm/sec (±1.6), which constituted a reduction of 33% and 72% from control conditions, respectively. Temperature manipulations were highly weather dependent due to a surprising lack of summer solar energy; they did not approach levels which would be considered detrimental to steelhead.

We found that growth was positive (2.5–9.4% increase in mass) across treatments in all but the fourth trial, which was consistently negative (7.5–14% decrease) across treatments. There was a significant difference in growth between treatments ($P = 0.019$, one-way ANOVA). Movement

downstream was strongly dependent on reductions in depth and flow in the stock unit, and movement into collection pools was influenced by reductions in depth in the stock unit.

Our results indicate that reductions in stream flow may result in less predictable microhabitat shifts and movement of juvenile fish, as well as differences in growth. Future work is needed to determine how these responses to stream flow interact with density dependence and to successfully assess the effect of elevated temperature.

New tools for evaluating restoration in the Pacific Northwest

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There have been enormous efforts to recover endangered salmonid populations throughout the Pacific Northwest. But despite decades of effort, the long-term survival of many populations remains in doubt. This has led to new initiatives to assess and monitor salmon restoration efforts and fostered the creation of national and regional databases of salmon restoration work. These databases make accessible an unprecedented quantity of data regarding the implementation of restoration projects. Initial analysis of the Pacific Northwest Salmon Habitat Project database suggests that greater scrutiny is needed to understand the motivations for restoration project choice. We ask the simple question: Is there a good correspondence between habitat need and choice of restoration action? Here we presented information tools needed to answer the fundamental question: If a habitat assessment is done, are projects chosen that would repair the problems identified in the assessment?

Hook and line survey of shelf rockfish in the Southern California Bight: Summary of 2004–2008 data

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The NWFSC's Fisheries Resource and Analysis and Monitoring Division conducts an annual hook and line survey for shelf rockfish (genus *Sebastes*) in the Southern California Bight. The project, which began in 2002, targets demersal rockfish species associated with rocky, untrawlable habitats that are generally not sampled well by the division's other groundfish monitoring cruises. The hook and line survey is a collaborative effort with Pacific States Marine Fisheries Commission and the sportfishing industry in southern California. The 2008 field season was the fifth year in a time series of catch-per-unit-effort data and other biological parameters that are used to calculate an index of relative abundance for several important rockfish species including bocaccio (*S. paucispinis*), vermilion rockfish (*S. miniatus* and *S. crocotulus*), greenspotted rockfish (*S. chlorostictus*), and speckled rockfish (*S. ovalis*).

During the first four years of the survey, 43 unique species have been caught, including 33 rockfish species. Bocaccio and vermilion rockfish are the most commonly observed species, accounting for 61% of all individuals encountered during the first four years of the survey. The length composition for bocaccio from the 2008 survey is characterized by several above-average year classes which contrast with results from 2004 where a single year class accounted for the vast majority of the biomass. Length frequency data for vermilion rockfish suggest this species experiences more stable recruitment than bocaccio. A generalized linear model was developed to track population trends for several rockfish species, and preliminary analyses suggest generally flat trajectories for bocaccio, vermilion rockfish, and greenspotted rockfish.

Future efforts include expanding the collection of environmental and oceanographic data during sampling, including the acquisition of seawater temperature, dissolved oxygen, salinity, pH, and light intensity information at depth from all survey sites. These data may provide informative covariates reducing uncertainty around population estimates and may also be useful in tracking shifts in oceanographic regimes in the region. Hook and line survey data are also being analyzed for their utility in studying the efficacy of marine protected areas. The survey is improved by its collaboration with the sportfishing industry and has strengthened the working relationship between NOAA Fisheries Service and stakeholders in the region.

Genetic analysis of Southern Resident killer whale feces reveals prey selection

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Recovery plans for endangered Southern Resident killer whales (SRKW, *Orcinus orca*) have identified reduced prey availability as a possible risk to the population. In order to assess this risk, we began a prey selection study in the whales' San Juan Island and Puget Sound range in 2004. By following the whales in a small boat and using a fine mesh net, we have collected more than 200 fecal samples over the last 4 years. Through molecular genetic analysis of the fecal samples, we are able to identify SRKW prey species. Prey detection from fecal samples has provided a new dimension in killer whale diet studies. Fecal samples represent prey consumed over an extended period of time and are therefore expected to be less biased, or at least have different biases, than fish remains collected immediately after a predation event at the surface.

Fecal analysis indicates that Chinook salmon (*Oncorhynchus tshawytscha*), a relatively rare species, is the primary prey species consumed during the whales' San Juan Island spring-summer

range (May-September). Chinook salmon are present in nearly 80% of all fecal samples collected during the spring and summer months. This finding strongly supports previous and concurrent studies based on prey remains (fish tissue and scales) collected from the surface of the water. During the fall and winter months, when the whales spend more time in central Puget Sound, fecal samples have shown that the diversity of their diet increases. During the fall and winter, other species such as chum salmon (*O. keta*), coho salmon (*O. kisutch*), sole, or lingcod (*Ophiodon elongatus*) are present in over half the total fecal samples. Although we have collected approximately one-third the number of fall-winter fecal samples as spring-summer samples, the increased diet diversity seen in the fall and winter months by fecal analysis is corroborated by analysis of fish remains. In addition to the aforementioned prey species, we have also identified steelhead (*O. mykiss*), Pacific halibut (*Hippoglossus stenolepis*) and rockfish as prey items through fecal analysis.

Future work includes analyzing fecal samples for the presence of additional fish species as well as squid and quantification of the relative amounts of different fish species when more than one species is present within a single scat. In summary, fecal samples have greatly improved our understanding of SRKW diet, giving us a look at the total picture of prey selection. While fecal samples help to illustrate diversity in the whales' diet, they also support other studies in showing that Chinook salmon are the whales' primary prey item. These results are likely to be of significant value in guiding management actions to recover the SRKW population.

Assessing the feeding ecology of beluga whales in Cook Inlet, Alaska, using chemical tracers

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Cook Inlet beluga (white) whales (*Delphinapterus leucas*) have been declining in number since 1994 when the National Marine Fisheries Service began conducting annual aerial surveys of the population. In response, Cook Inlet beluga whales were listed as a protected species under the Endangered Species Act in October 2008. Initial efforts to understand the decline in the Cook Inlet beluga population focused on subsistence harvest effects; however, this is no longer thought to be the predominant factor influencing the belugas' decline. Another possible contribution to the decline of these whales may be a lack of adequate prey. Regrettably, the specific diet of these whales is largely unknown, so it is difficult to evaluate the impact of declining fish runs on the Cook Inlet beluga population. It is known however that returning adult salmon are an important prey species of these whales, particularly during late spring through early autumn. Unfortunately, since 1990, commercial fisheries for sockeye salmon (*Oncorhynchus nerka*), as well as sport fisheries for Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*), have reported declines in a number of fish runs in the Inlet.

The focus of this project was to use chemical tracer data to help infer the predominant prey of this population of white whales. Specifically, between 2001 and 2008 blubber and skin samples from a combination of catch and release, stranded, and subsistence harvest Cook Inlet beluga whales were collected along with representative samples of their most likely whole-body fish prey (including nonsalmonid species), and all of these samples were analyzed for their fatty acid compositions and their 15N/14N and 13C/12C stable isotope ratios. From these data, a semiquantitative model based on a combination of these fatty acid and stable isotope results was developed to assess what combination of specific prey most likely represents the predominant prey of Cook Inlet beluga whales. The preliminary conclusion obtained as a result of this study continues to point to salmonids, in particular chum salmon (*O. keta*), as the most important contributors to the diets of these whales during spring and summer.

Taking it in stages: A life-cycle analysis of factors influencing the status of endangered spring Chinook salmon

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A critical element of recovery planning is rigorously identifying key limiting factors. Efforts to restore habitat for Pacific salmon (*Oncorhynchus* spp.) have been a focus of many plans to improve their status. However, the potential of habitat restoration to drive recovery of Pacific salmon depends on other important factors influencing their survival such as alterations to the hydrosystem used for migration, competition and interbreeding with hatchery salmon, harvest rates, and climate influences on survivorship in the ocean. A life cycle model is a useful framework for assessing the relative importance of each of the various factors influencing salmon survivorship at each life stage from egg to fry to smolt to ocean adult and finally to spawner.

We focus on the wild, spring-run Chinook salmon (*O. tshawytscha*) population of the Wenatchee River basin to illustrate the utility of life cycle models for comparing the various threats a population may face. Our goal is to assess the potential for habitat actions to improve population status in the context of other important factors limiting their survival. This analysis shows how much dependence can be placed on habitat restoration to restore salmon in the face of other influences including survivorship through the Columbia River hydrosystem, interactions with a large population of hatchery fish, and climate effects on ocean survival. This is a work in progress.

Acoustic characterization of scattering layers of dominant fish and zooplankton species off the west coast of the United States and Canada

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Pacific hake (*Merluccius productus*) is an important commercial and ecological marine fish off the west coast of the United States and Canada. Acoustic surveys of Pacific hake involving scientists from both nations have been conducted on either a triennial or biennial basis since 1977. In recent years, the Simrad EK series echo sounders (EK500/EK60) consisting of multiple frequencies have been the primary acoustic sampling instrument. Ground truthing was obtained by biological sampling using midwater and bottom trawls at various depths from about 100 m to as deep as 500 m. The intercomparison of trawl data to the acoustic signatures—including the volume backscattering strength, an absolute quantity, and the frequency dependence, a relative quantity—allow us to verify the commonly accepted theoretical interpretations and advance towards establishing automated identification and classification algorithms.

We presented a variety of echograms with distinct acoustic signatures, representing two stages of identification and classification. The first is to determine whether the echograms are hake or nonhake, while the second is to further classify what type of marine organisms corresponds to the nonhake echograms. Most of the characteristics of the hake echograms can be explained based on the scattering physics. However, some hake echograms are different from the theoretical predictions of swim bladder-bearing fish and require additional investigation and interpretation.

Life history and genetics of chum salmon in the southern portion of their range (California, Oregon, and Columbia River) and possible impacts of climate and habitat changes

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Spawning populations of chum salmon (*Oncorhynchus keta*) historically extended as far south as the San Lorenzo River in California and 322 km upstream in the Sacramento River. In 1905–1906 chum salmon juveniles were the most abundant salmon species in streams surveyed between the Sacramento and Columbia rivers. Today, these populations have greatly declined, and in the Columbia River are now listed under the Endangered Species Act as a threatened species. Little life history, genetic, or other biological information has been developed on these fish. This information is important as southern populations may represent remnants of historical populations with characteristics essential to the successful restoration of depleted present day populations.

Information developed in conjunction with the Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, and U.S. Fish and Wildlife Service includes demographic, genetic, and life history data, such as presence or absence of spawning populations, age structure, and timing of migrations. Preliminary microsatellite genetic data indicate population structure among coastal populations and differences from interior and Puget Sound runs. Coastal populations may also contain unique genotypes and adaptations which may be important as increasingly rapid changes in climate, pollution impacts, and development expose salmonids to pressures beyond their ability to adapt, forcing further declines and even extinction.

All together now: Demographic synchrony and population structure in spring/summer Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in the interior Columbia River basin

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Efforts to conserve species can be hampered by a lack of understanding of the composition and structure of population units, which may be important for long-term species persistence and recovery. Demographic data, such as spawning counts, are one of several lines of evidence useful in determining population structure. We examined pairwise Pearson correlations between time series of abundance estimates of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) spawners in streams across the interior Columbia River basin to look for synchronous patterns as evidence of population structure and demographic independence. The population structure of these fishes was delineated largely using other evidence (genetic markers, proximity between spawning aggregations, morphological and phenotypic traits, habitat and ecoregion similarities, etc.) because inferring population structure from demographic synchrony using estimates of adult spawner abundance can be problematic. This life stage integrates the fish response over several common and potentially synchronizing influences that act at both small and large spatial scales—climate, ocean conditions, the four Hs (habitat, hydropower, hatcheries, harvest)—and over several life history stages.

Cognizant of these potential difficulties, we used pairwise correlations as distance measures in a hierarchical cluster analysis. Overall, we found that the majority of correlations were positive, and the percentage of positive correlations was slightly higher for Chinook salmon (75%; 6% were significant) than steelhead (72%; 0% were significant). Chinook salmon stream counts largely clustered within existing population structures, but the clustering structure of steelhead was less clear. We also investigated the "Moran effect," the relationship between pairwise correlations and their geographical distances. For Chinook salmon, there was a well-defined decline in correlation with geographic distance for stream count comparisons within major population groups (MPGs), and a significant but gradual decline within evolutionarily significant

units (ESUs). There was no relationship between correlation and distance among comparisons outside of their ESUs. For steelhead, there was no discernable relationship in stream count comparisons within MPGs or ESUs, and in comparisons outside of ESUs correlations slightly increased with distance.

Despite the complicating factors with using demographic data to assess population structure, the degree of population synchrony as measured by the patterns of correlations, the results of the clustering, and the relationships between distance and correlation generally supported the population MPG/ESU designations for Chinook salmon but results for steelhead were inconclusive.

A record of *Aldrovandia oleosa* (Notacanthiformes: Halosauridae) from the eastern North Pacific

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In 2007 a specimen of *Aldrovandia oleosa* Sulak was captured by scientists of the National Marine Fisheries Service in the Pacific Ocean off southern California. Although *A. oleosa* has been found in the deep waters of the western Atlantic, the tropical eastern Atlantic in the Gulf of Guinea region, the western Indian Ocean, and the eastern central Pacific and Chile, it had not previously been recorded in the North Pacific.

Scientific data management at the Northwest Fisheries Science Center

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The Scientific Data Management Team (SDM), in the NWFSC's Operations, Management and Information Division develops and maintains a coordinated approach to managing data and enabling their use in scientific research related to endangered species recovery and marine species management in the Pacific Northwest. To this end, SDM provides expertise in database design, application development, and geographic information systems for desktop clients and over the Internet.

SDM works with internal and external researchers and staff to collect, synthesize, organize, and report diverse sets of data, including restoration and recovery project data (Pacific Coastal Salmon Recovery Fund, Pacific Northwest Salmon Habitat Project), monitoring and evaluation data (Integrated Status and Effectiveness Monitoring Program, habitat, water quality), and biological and physical data (salmonid abundance, artificial propagation, genetics, bird predation, barge transport, oceanographic). Additionally, we offer tools, applications, and expertise to facilitate analysis and collaboration among Center staff and with external partners (ArcGIS Server and online mapping, Java and javascript programming, ArcSDE database project space, Matlab/STAR-P modeling, Oracle Collaboration Suite).

Effect of mesoscale physical oceanographic variability on zooplankton community structure in shelf and slope waters from central Oregon to northern California

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Upwelling is more or less a linear process in waters north of Heceta Bank, Oregon. However immediately south of Heceta Bank (lat 44°N), the California Current starts to break up into eddies and filaments, caused by a meandering upwelling jet over southern Heceta Bank and by variations in intensification of the field of the winds at and south of Cape Blanco, which leads to stronger upwelling there and instabilities in the upper layer flows.

This poster showed the influence that these mesoscale features have on copepod distributions and copepod community structure. Coastal communities can be found far offshore due to transport in large filaments that develop off Cape Blanco. Nearshore communities are similar up and down the coast, however mid and outer shelf communities can be found well offshore due to their entrainment in offshore advection of mesoscale eddies and filaments. Thus these physical features can transport a high biomass of copepods seaward, thereby fueling an enriched food chain far offshore in waters that are not very productive. This also has implications on the vertical flux of copepod carbon to the deep sea.

Microgeographic variation of reproductive timing under different thermal regimes: Local adaptation despite dispersal?

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Gene flow generally prevents local adaptation, and hence the relative strength of natural selection and dispersal is a key for understanding microevolutionary processes. Partially connected populations faced by different selective regimes are a good system to study contrasting forces of selection and gene flow.

I investigated the difference in reproductive timing of stream dwelling Dolly Varden (*Salvelinus malma*) among 32 tributaries (each <50 RKM in length) of the Sorachi River in central Hokkaido, Japan, which are supposed to be under different thermal regimes (temperature-constant spring-fed tributaries vs. temperature-variable nonspring-fed tributaries). The spawning season lasted up to 4 months (mid-August to mid-December), resulting in a total of 1,206 records of spawning activities (271 spawning behaviors, 935 spawning nests). There was no strong peak for the spawning activities, suggesting a weak stabilizing selection at the watershed level. At the tributary level, some tributaries showed different reproductive timing, indicating local adaptation. In most tributaries, however, spawning lasted continuously without a clear peak regardless of the thermal regimes. This indicates that the gene flow prevents local adaptation, or alternatively, small population size might constrain adaptive divergence among tributaries due to strong genetic drift.

Species and stock identification of juvenile salmon tissues collected from the stomachs of double-crested cormorants (*Phalacrocorax auritus*)

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A multiagency study begun in the 1990s has documented the substantial impact of fish-eating birds on the survival of juvenile salmon in the Columbia River basin. One area of study is East Sand Island near the mouth of the Columbia River, which is inhabited by the largest colony of double-crested cormorants (*Phalacrocorax auritus*) on the Pacific Coast of North America. East Sand Island cormorants prey on a broad diversity of fish species and consume millions of juvenile salmon each year. Bones and other diagnostic tissues recovered from the stomachs of lethally sampled cormorants are used to determine the family of fish consumed, but identification of fish species is less successful. Moreover, information on stock origins is only available when PIT or other fish tags are recovered.

In 2007 we conducted a pilot study to determine whether partially digested fish tissues sampled from bird stomachs would yield adequate DNA to identify fish species and genetic stock of origin. Genomic DNA was isolated from frozen samples of salmon tissues collected from the foreguts (stomach and esophagus) of double-crested cormorants on East Sand Island. Species identification using the mitochondrial DNA fragment COIII/ND3 was successful for 72 of 72 samples collected from 18 cormorants. Steelhead (*Oncorhynchus mykiss*) were the most frequent salmonid in the stomach samples (43%), followed by Chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) (26% each). Two cutthroat trout (*O. clarkii*) (3%) and one sockeye salmon (*O. nerka*) (1%) were also identified. We also used the 13 standardized GAPS (genetic analysis of Pacific salmon) consortium microsatellite loci to examine the stock origins of fish identified as Chinook salmon. Of 19 individuals, 15 were successfully genotyped at 8 or more of the 13 loci. GSI (genetic stock identification) analysis indicated that our samples contained individuals from spring and fall runs and included fish from 6 different genetic stock groups. We identified Chinook salmon from the lower Columbia River as well as from the upper

Columbia and Snake rivers, suggesting that predation by East Sand Island cormorants impacts Chinook salmon from throughout the Columbia River basin.

Suppressive subtractive hybridization reveals differences between *Vibrio parahaemolyticus* isolates from the Puget Sound region and the pandemic strain

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Pathogenic strains of the common marine and estuarine bacteria, *Vibrio parahaemolyticus* (Vp) can induce severe gastroenteritis in humans following the consumption of uncooked seafood. Similar to other *Vibrios*, Vp is generally involved in environmental nutrient cycling and is capable of substantial genetic exchange, allowing it to expand into diverse ecological niches. The full genome of a recently emergent pandemic serotype (O3:K6; tropical and subtropical waters, 1995–present) has been published; however, this serotype does not match isolates linked to outbreaks in the Pacific Northwest region of the United States.

We utilized suppressive subtractive hybridization (SSH) to compare the genomic content of three Puget Sound Vp isolates (two environmental and one clinical) with the global pandemic strain. SSH libraries were created for each strain using genomic DNA from the tester (Puget Sound) strain and driver genomic DNA from the pandemic strain. An average of 275 clones were sequenced from each library, revealing features of the Puget Sound isolates that are absent from the genome of the global pandemic strain. While approximately one third of the features identified encode proteins of unknown function, the remaining features represent a wide variety of functions, with major representation of genes involved in metabolic processes, nucleic acid modification, and DNA mobilization. Very few genes were shared among the three libraries, highlighting the diversity of Vp in the Puget Sound region. This study expands our current understanding of the potential scope of the Vp genome while revealing some genomic characteristics of local subpopulations.

Gene expression profiles in zebrafish brain after acute exposure to domoic acid at symptomatic and asymptomatic doses

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Domoic acid (DA) is a neuroexcitatory amino acid that is naturally produced by some marine diatom species of the genus *Pseudo-nitzschia*. Ingestion of DA-contaminated seafood by humans results in a severe neurotoxic disease known as amnesic shellfish poisoning (ASP). Clinical signs of ASP include seizures and neuronal damage from activation of ionotropic glutamate receptors. However, the impacts of DA exposure at levels below those known to induce outward signs of neurobehavioral exicitotoxicity have not been well characterized.

To further understand the mechanisms of neurotoxic injury associated with DA exposure, we examined the transcriptome of whole brains from zebrafish (*Danio rerio*) receiving intracoelomic injection of DA at both symptomatic and asymptomatic doses. A majority of zebrafish exposed to high-dose DA (1.2 μg DA/g) exhibited clinical signs of neuroexcitotoxicity (EC50 of 0.86 μg DA/g) within 5 to 20 min of intracoelomic injection. All zebrafish receiving low-dose DA (0.47 μg DA/g) or vehicle only maintained normal behavior. Microarray analysis of symptomatic and asymptomatic exposures collectively yielded 306 differentially expressed genes (1.5-fold, $p \leq 0.05$), predominately represented by signal transduction, ion transport, and transcription factor functional categories. Transcriptional profiles were suggestive of neuronal apoptosis following an overwhelming of protective adaptive pathways. Further, potential molecular biomarkers of neuropathic injury, including the zebrafish homolog of human NDRG4, were identified and may be relevant to DA exposure levels below that causing neurobehavioral injury.

In general, DA-modulated gene expression was consistent with other model species, thereby validating zebrafish as an appropriate vertebrate model to study mechanisms of DA neurotoxicity. These data provide a basis for identifying pathways of DA-induced injury as well as biomarkers of asymptomatic and symptomatic DA exposure levels.

The effects of variable oceanographic conditions on forage fish lipid content and fatty acid composition in the northern California Current

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We evaluated the benefit of lipid and fatty acid content in four species of forage fish—northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), Pacific herring (*Clupea pallasii pallasii*), and whitebait smelt (*Allosmerus elongatus*)—to serve as biological markers of ocean conditions in the California Current large marine ecosystem (CCLME) during the contrasting oceanographic years of 2005 and 2006. Upwelling was severely curtailed in the CCLME in 2005, leading to delayed biological productivity, whereas upwelling was more normal in 2006, beginning during the spring period. Total lipid content range was lower for all forage fish species in 2005 (0.37–23.52% wet mass) than measured in 2006 (1.31–26.37% wet mass). Principal components analysis described 78% of the variance within the multivariate lipid and fatty acid data set using just two PC axes and PC2 was sufficient to explain lipid and fatty acid variations by sampling season ($r^2 = 0.22$, $p < 0.01$).

Using ratios of fatty acid biomarkers docosahexaeonic acid (DHA) and eicosapentaeonic acid (EPA) we detected a transition from a diet composed primarily of dinoflagellate origin in early 2005 to a diet of diatom-based productivity by late summer 2005, a shift due to prey availability which was corroborated through phytoplankton sampling. Moreover, we found higher levels of macrozooplankton carnivory, substantiated by the accumulation of monounsaturated eicosenoic and erucic fatty acids in Pacific herring and northern anchovy in 2006 relative to 2005. Lipid levels were negatively correlated ($r^2 = 0.38$, $p = 0.01$) with DHA concentrations, and positively correlated ($r^2 = 0.41$, $p < 0.01$) with EPA values. Accumulation of different lipid and fatty acid profiles in the forage fish community demonstrates how ocean conditions and productivity in the CCLME can affect food web structure. The implication of this variation to the health and success of the forage fish community and to subsequent user groups (e.g., salmon, important groundfish species) has yet to be determined.

Developing a decision support system to systematically assess the broad diversity of threats to lower Columbia Chinook salmon, a test case for the 5-year status review

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We looked at the wide variety and complexity of threats facing threatened and endangered species, developed a method for conducting a systematic risk/threats analysis for the 5-year status review, and applied those methods to Pacific salmon. To evaluate what is keeping salmonid populations and evolutionarily significant units (ESUs) from attaining recovery, we first identified current limiting factors and threats to the lower Columbia River (LCR) Chinook salmon (*Oncorhynchus tshawytscha*) ESU. Due to the large number of populations in the LCR Chinook ESU (32), we chose to concentrate our efforts on three populations, one from each run timing, and at least one from each state, as well as populations with varying limiting factors (Sandy late fall, Upper Cowlitz spring, and Big Creek fall).

Combining and synthesizing many disparate data, in this case 46 metrics per population, in a valid and meaningful way presents a practical problem. One way to overcome this problem is to utilize a decision support system (DSS) approach. A DSS is a computer-based tool that can be used to evaluate information and aid managers in decision making. Our fuzzy logic DSS evaluates whether there are major factors limiting the recovery of a population. Resulting values for our three test populations are as follow: Big Creek fall Chinook salmon = 0.75, Sandy River late fall Chinook = 0.66, and Upper Cowlitz spring Chinook = 0.80. Interpreting these results, we can say we are moderately certain that the Upper Cowlitz spring Chinook population faces major risk factors limiting recovery. We are somewhat less certain that the Big Creek fall Chinook population faces major risk factors. With a final score of 0.66, we are fairly uncertain regarding major risk factors for the Sandy River late fall Chinook population; however, because the value is still far from 0.0, it may be safe to assume the population faces minor to moderate risks.

Are West Coast groundfish observer data just collecting dust?

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The NWFSC's West Coast Groundfish Observer Program collects fisheries independent data from the West Coast commercial groundfish trawl and fixed gear fleets. Data collected include fishing effort information, estimates of retained and discarded catch including species composition, biological data from discarded catch, and interactions and sighting of protected species.

Observers and fishermen tend to believe that observer data are not used, that after collection, the data sit in a database somewhere gathering dust. That is not the case with West Coast groundfish observer data. Data users include fisheries managers, stock assessors, marine mammal scientists, and seabird scientists, to name a few. In conjunction with other data sets, the data are used to set quotas, estimate historical catch, estimate bycatch of protected species, and estimate stock abundance. In addition, observer data can inform scientists conducting research on fish migration, gear efficiency, and fish and invertebrate distributions.

Education at NOAA's Northwest Fisheries Science Center

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The America COMPETES (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science) Act of 2007 mandates NOAA to educate the public about ocean, coastal, Great Lakes, and atmospheric science and stewardship. Northwest Fisheries Science Center (NWFSC) Education works on all levels of NOAA, including the NOAA Office of Education, NOAA West regional collaboration team, Northwest regional line offices, and with the NMFS National Education Coordinator and the Fisheries Education Council. NOAA has adopted the Ocean Literacy principles, which define an "ocean literate" person. NWFSC education coordinators participate in diverse education activities, including teacher and student workshops, festivals, field experiences, classroom presentations, and events with partners such as the Seattle Aquarium and Washington Sea Grant. All NWFSC staff are encouraged to get involved in Active Center Educators (ACE), a group that meets regularly to discuss education activities and opportunities, and work toward a more ocean literate public.

Seasonal and interannual fluctuations in adult and juvenile *Euphausia pacifica* and *Thysanoessa spinifera* abundance for the years 1998 through 2006 in the California Current

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Understanding the annual and seasonal variability in abundances as well as the distribution of *Euphausia pacifica* and *Thysanoessa spinifera* and how these species of krill respond to climatic changes may prove useful for fisheries management decisions, once an ecosystem approach to management is adopted, because these species are the primary food items for a broad variety of fish, bird, and mammal species. We have combined data from multiple scientific sampling projects and cruises to produce coast-wide charts showing the distribution and biomass of euphausiids in plankton net samples collected at night from 1998 through 2006, along transects ranging from northern California to northern Washington. Several hot spots were identified and shown.

Development of a multiplex assay to generate a comprehensive mRNA profile to identify potential growth rate indicators in salmon

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The growth rate of Coho salmon (*Oncorhynchus kisutch*) post-smolts is strongly correlated to the returning adults the following year (i.e., survivorship). The goal of this project is to develop indicators of growth rate as a tool to predict the health and abundance of returning salmon. Previous studies have relied on measuring circulating hormone levels in the blood. This practice has several limitations; most notable are the volume of plasma and the size of the individual needed to accurately measure the proteins in the blood. Previous work has shown a strong correlation of circulating insulin-like growth factor I (IGF-I) protein to IGF-I messenger RNA (mRNA) levels in the liver.

The focus of this study is to explore a more comprehensive panel of fish growth-related transcripts using Quanti-gene multiplex technology from Panomics Inc., Fremont, California. This technology permits the simultaneous quantification of multiple targeted mRNAs within a single tissue homogenate using sequence specific probes and requires no reverse transcription or amplification as with polymerase chain reaction. Initial results have confirmed the relationship between IGF-I mRNA and circulating IGF-I protein and revealed other growth-related factors as potential molecular indicators of grow status in salmon. The amount of tissue required to generate these data requires drastically less material and can be used on alevin and parr to elucidate changes in transcriptional profiles in response to a variety of stimuli including growth, pollution exposure, and reproductive status in a variety of tissues.

Latitudinal gradients in copepod community composition in the northern California Current and southern Gulf of Alaska during years of varying ocean conditions

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During summer from 1998 to present, various research programs have sampled zooplankton from the central California Current north to the southern Gulf of Alaska, a distance of 2,000 km. Comparisons among these programs are of interest because there is a strong latitudinal gradient in ocean conditions among regions, particularly in the strength of coastal upwelling. Off California and southern Oregon, upwelling is strong and occurs over most months of the year. Upwelling is less strong and highly seasonal off central and northern Oregon, relatively weak off Washington and Vancouver Island, and completely lacking off northern British Columbia and southeast Alaska. Due to these latitudinal gradients in hydrography, we expect to identify faunal boundary regions. Sufficient sampling occurred during the 1998 El Niño event, the relatively warm year of 2003, and the cold years of 1999, 2000, and 2002 to allow for comparison of differences in climatic forcing and ecosystem response among regions.

We found latitudinal and interannual differences in hydrography, chlorophyll, and copepod community structure. Waters to the south were saltier, had higher chlorophyll concentrations, and had higher copepod species richness. The warm years of 1998 and 2003 had higher copepod species richness, warm water and offshore copepods were more abundant, and both warm and cold water copepods were found further to the north. In comparison, the cold years of 1999 to 2002 had lower copepod species richness, cold water copepods were more abundant, and warm water copepods had a more southerly distribution.

Renibacterium salmoninarum infection in Chinook salmon—how widespread is it outside the hatchery?

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Infection by *Renibacterium salmoninarum* can result in bacterial kidney disease, a chronic and debilitating condition that is recurrent in fish hatchery stocks. Disease monitoring programs are typically directed at adult females returning to the hatchery in order to cull infected broodstock. As a result, few efforts have been directed at assessing other life history stages or at naturally spawning adults.

To track fluxes in infection prevalence, efforts to monitor multiyear cohorts of Chinook salmon (*Oncorhynchus tshawytscha*) at different life history stages have been initiated. Prerelease hatchery smolts, in-river outmigrants, and returning adults (hatchery and natural spawn) were sampled from two Columbia River populations (Yakima River and Lostine River), whereas prerelease hatchery smolts, early marine post-smolts, and returning adults (hatchery and natural spawn) were sampled from a Puget Sound hatchery population (Skagit River).

The first year's data reveals significant differences in prevalence among the populations, ranging from 3.1% to 62.5%. Because infection data were collected in concert with physiology and ecology field studies, parameters such as maturation state and broodstock year can be assessed as risk factors. This type of fundamental data can inform disease management strategies, and can identify significant epidemiological factors.

Family competition in a selected strain of coho salmon (*Oncorhynchus kisutch*)

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The effect of diet regime on, between, and within family competition was tested using a domesticated strain of coho salmon (Dømsea strain, Aquaseed Inc., Rochester, Washington). Fish from 10 full-sib families were individually tagged and reared in a pooled community tank and fed at a decreased ration to allow for study of competition within and between families for food. This design was repeated in a second set of tanks, but fish were fed ad lib to allow for maximum growth. A previous study (Neely et al. 2008. Comparison of growth, feed intake, and nutrient efficiency in a selected strain of coho salmon (*Oncorhynchus kisutch*) and its source stock. Aquaculture 283(1–4):134–140.) showed that Dømsea fish outperformed Wallace River coho salmon (the parental stock) when fed to satiation. Also shown was a tendency for the fish to exhibit a bimodal size distribution when food was restricted.

Results from the current study will compare growth (weight, length, and condition factor) in families reared under the two regimes and assess whether family performance (rank) differs between treatments. Changes in family rank may indicate that selection programs may need to be tailored to rearing conditions.

Evaluating aquatic invertebrate food quality using carbon and nitrogen: A comparison among salmon-bearing streams in the Salmon River basin in central Idaho

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Prey availability and prey quality clearly impact growth and survival of juvenile salmonids, yet studies have rarely quantified these prey characteristics and their implications for juvenile fishes. This study examined both the quality and availability of aquatic invertebrate prey from salmon-bearing streams in the Salmon River basin in central Idaho. We hypothesized that greater nutritional quality (reflected by increased nitrogen content) and availability of invertebrate prey would positively affect the local fish community as observed through increases in average fish size and abundance.

First, we evaluated the efficacy of using whole body nitrogen content and carbon/nitrogen (C:N) ratio as measures of the nutritional quality of invertebrates from the orders Ephemeroptera and Trichoptera. Then we quantified prey availability with benthic and drift aquatic invertebrates density. Last, the abundance and size distribution of juvenile salmon populations were quantified using snorkel surveys and used to investigate the effect of food quality and quantity on local fish assemblages. Our results indicate that the nitrogen content and C:N of Ephemeroptera and Trichoptera varies among streams and may be a useful surrogate for food quality.

Tools useful for qualitative forecasting of adult salmon returns and for understanding the underlying climate and oceanographic mechanisms which may control rates of return

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This poster described how physical and biological oceanographic conditions affect the growth and survival of juvenile salmon in the coastal waters of the northern California Current off Oregon and Washington. As an aid to understanding relationships between oceanographic conditions and juvenile salmon, we presented a number of indices based on physical, biological, and ecosystem metrics that are useful for forecasting the survival of salmon up to 1 to 2 years in advance and that define the term "ocean conditions" in a more precise manner.

Most of the information is based on our own observations of the physical and biological characteristics of coastal waters made during frequent oceanographic cruises to the coastal upwelling ecosystem off the Pacific Northwest since 1996. This information is presented on the Center's Web site (see "Ocean Index Tool") and is updated twice each year, in late spring after spring run fish have entered the ocean and in November and December after we have finished analyzing data collected during that calendar year.

Paralytic shellfish toxin resistance mechanisms in bivalves

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At least two paralytic shellfish toxin resistance strategies exist in bivalves, incorporating two very different groups of proteins: the voltage gated sodium channel and soluble saxitoxin (STX) binding proteins. These proteins have the ability to bind saxitoxin and its derivatives with high affinity. In the softshell clam (*Mya arenaria*), it was recently reported that a single amino acid substitution in the sodium channel conferred nerve resistance to saxitoxin. We have since examined the amino acid sequence of sodium channels from a variety of other bivalve species including Washington butter clam (*Saxidomus gigantea*), Pacific razor clam (*Siliqua patula*), ocean quahog *(Arctica islandica*), hard clam (*Mercenaria mercenaria*), Manila clam (*Venerupis philippinarum*), and others collected from the U.S. Pacific and Atlantic coasts.

A similar resistance strategy appears to be involved in shellfish resistance and we observed identical amino substitutions of the STX binding domains of the sodium channel. Soluble STX binding proteins activity was also investigated in these species and, in the case of *S. giganteus*, was determined to be highly localized in the siphon and demonstrating nanomolar binding affinities with STX, dcSTX and NeoSTX. In addition, ubiquitous low level STX binding activity was observed across all isolated tissue types in *S. giganteus* and white-sand macoma (*Macoma secta*), indicating that circulation of the protein through the hemolymph was likely.

The Southern Resident killer whale watching industry of the greater Puget Sound, Washington—Who are they? What have we learned?

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Orca whales (*Orcinus orca*), also known as killer whales, are cultural icons for the human residents of the Pacific Northwest's Puget Sound. The Southern Resident killer whales (SRKW) recently received an endangered listing under the Endangered Species Act and are protected under the Marine Mammal Protection Act. In a research atmosphere where ecosystem science is emphasized, it is instinctive to discuss the biological elements of an ecosystem. However, when reflecting on an ecosystem, it is important to understand that humans are part of the ecosystem as well. In this case, while biological research on the SRKW itself is beginning to answer ecosystem questions, there is little information on the connection of these animals and humans.

As social scientists, we study the human dimension of ecosystems, working to better understand people and their relationship to marine resources. In this instance, we are interested in better understanding the relationship of people to the SRKW. Specifically, we have identified a unique relationship between the whale watching industry of the Greater Puget Sound and the SRKW. We aim to more clearly understand this connection. As with fishermen who depend on healthy fish stocks, this industry depends on a healthy and resilient population of SRKWs.

This poster discussed the results of our social science research, which aims to describe the people involved in the industry. Data were collected using a survey tool and interviews. Demographic information, employment history, insights into the reasons people participate in the industry, and descriptions of whale watching company characteristics are examples of the type of information collected. Together this information contributes to a greater understanding of the connection industry members have to the significant marine resource that is the SRKW.

Using ecological thresholds to inform benchmarks for ecosystem-based management in Puget Sound

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One of the major challenges to implementing a plan for ecosystem-based management (EBM) in Puget Sound is a lack of scientifically based approaches for defining ecosystem-level management targets. We outlined an approach for identifying management benchmarks that is based on the existence of nonlinearities in the relationship between fundamental attributes of the ecosystem and human-induced perturbations. In this approach, we 1) identify a set of ecosystem attributes, 2) use a food web model to simulate increasing levels of perturbation to the ecosystem and measure the response of the attributes to those perturbations, 3) locate a threshold on the ecosystem attribute-perturbation curve when the relationship between attribute and perturbation is nonlinear, 4) identify empirically-tractable indicators for the ecosystem attributes which are tightly correlated with the attribute values observed in the simulations, and 5) suggest methods for designating management benchmarks.

We illustrated this approach using a marine food web model, which allows us to measure the response of seven attributes (total consumption, the community respiration to biomass ratio, mean trophic level, Shannon diversity, resilience, total fisheries yield, and total fisheries value) to varying levels of fishing-induced mortality. Using these relationships to locate ecological thresholds can aid in determining the level of perturbation at which various aspects of ecosystem structure and function will be diminished. Thus this method for identifying ecological thresholds also draws attention to the trade-offs inherent to implementing EBM, and in so doing enhances the ability of policy makers to understand and manage natural ecosystems.

Euphausiid population dynamics in the coastal upwelling zone off the Oregon Coast

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We sampled hydrography, chlorophyll, copepods, and euphausiids during biweekly cruises at several hydrographic stations off Newport, Oregon (lat 44º40′N), and during bimonthly cruises over large-scale spatial grids (5–12 transect lines between lat 41º50′N and lat 44º40′N). The result is a unique data set showing temporal and spatial variations in the distribution and abundance of the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera* in the northern California Current.

Our zooplankton data set (2001–2007) encompasses warm and cold years and variable upwelling conditions. *E. pacifica* biomass was usually 10–50 mg C m^{-3}. *T. spinifera* biomass was generally less than 5 mg C m^{-3}. Average summer *E. pacifica* biomass showed a marked increase from inshore to offshore while *T. spinifera* biomass was from 1 to 5 mg C m^{-3} at all stations. Euphausiid growth rates were not affected by differences in upwelling. Euphausiid egg production was strongly affected as the timing of spawning seems to be tied to upwelling, therefore changes in upwelling are likely to result in changes in euphausiid spawning behavior.

Molting and growth of *Euphausia pacifica* and *Thysanoessa spinifera* in the coastal northeast Pacific

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While at sea, we incubated adult and juvenile euphausiids for measurement of vital rates (egg production and molting rates). *E. pacifica* and *T. spinifera* are the dominant euphausiids in coastal northeast Pacific—a dynamic environment, with seasonally strong upwelling. Instantaneous growth rate (IGR) experiments were conducted throughout 2001–2006, encompassing distinctly different oceanographic conditions: 2001, 2002, and 2006 were cold and productive; 2003–2005 were warmer and less productive. IGR experiments allow us to calculate growth in length in millimeters per day. Positive growth ranged from 0 to 0.9 mm per day. Negative growth occurred during all seasons, usually in larger animals of both species. Individual growth decreased as animals got larger but was highly variable.

Drop Acoustic Information System (DAISY)

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Target strength (TS) is a measure in dB of the ability of a target to scatter sound. Knowing the relationship of TS to fish size is necessary to generate biomass estimates from acoustic surveys. The United States and Canada jointly conduct surveys to measure the acoustic echo returns from Pacific hake (*Merluccius productus*) using 38 kHz echosounders.

Numbers of hake are derived from the total backscatter measured for the species by applying a 38 kHz TS-length relation of 20 log L – 68, where L is fork length in centimeters of a single fish. However, variability observed in TS of hake introduces uncertainty in assessment estimates. Stock assessment scientists have therefore focused research efforts to reduce uncertainty in the hake TS-length relation. Acoustic survey operations are conducted during daylight hours, however fish are generally too deep to collect accurate TS measurements from ship-mounted acoustic systems.

Potential TS biases from various sources of interference and from detection of multiple targets at depth required us to develop a tethered Drop Acoustic Information System (DAISY) which contains two echosounders and motion sensors. DAISY can be lowered closer to target depth to obtain daytime in situ TS measurements on hake. The system was calibrated at the surface using a standard 38.1 mm tungsten carbide sphere. Preliminary results of TS from juvenile hake indicate good agreement with the currently used TS-length relation.

The effects of temporal variations in fishing effort in the at-sea hake fishery

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Recent regulations limiting the bycatch of particular rockfish species in the Pacific hake (*Merluccius productus*) fishery have driven several changes in the fishery, including documented changes in fishing depths. Concerns about rockfish bycatch have led to speculation that tows made during daytime hours have reduced rockfish bycatch rates in comparison to nighttime tows. For the 2006 and 2007 seasons, in an effort to reduce widow rockfish (*Sebastes entomelas*) bycatch, a voluntary agreement between the vessels was proposed to focus fishing primarily during daylight hours and minimize nighttime fishing when possible. Fishing during nighttime hours was still conducted, but the data show a distinct effort shift towards increased fishing effort during daylight hours. Explorations into the historical differences in bycatch rates by time of day and the impact of reduced nighttime fishing effort were presented.

Trophic relationships and movement patterns of sixgill sharks (*Hexanchus griseus*) in the Puget Sound-Georgia Basin: Inferences about their ecosystem role from stable isotope analysis

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The sixgill shark (*Hexanchus griseus*) is a large predator and passive scavenger thought to forage across the entire marine food web, making it a good candidate as an indicator species for the overall health of the Puget Sound-Georgia Basin aquatic ecosystem. However, persistent questions remain about sixgill shark population demographics, diet information that clarifies energy flow, and movement patterns of the breeding population within the region.

We compared stable isotope ratios ($\delta^{15}N$ and $\delta^{13}C$) of white muscle tissue collected from more than 70 sixgill sharks to describe their trophic level within the aquatic food web and to clarify broad movement patterns. Nitrogen stable isotope ratios of sixgill sharks (mean $\delta^{15}N$: 16.5‰) were enriched relative to most other aquatic species, confirming that sixgill sharks represent one of the top trophic levels in the Puget Sound food web. Carbon stable isotope ratios of sharks, which are indicators of the sources of food web production, reflect strong spatial patterns of resource use. Sharks from central Puget Sound were exclusively subadults (150 cm to 315 cm total length [TL]) with highly enriched $\delta^{13}C$ ratios (mean $\delta^{13}C$: –12.8‰), possibly reflecting dependence on benthically derived nearshore primary production and suggesting little movement outside Puget Sound. Clustering of $\delta^{13}C$ ratios revealed two distinct groups of subadult sharks that could not be differentiated based on time of capture, size, or sex.

We are analyzing acoustic tag movements from a subset of animals in each group to determine whether the distinctive $\delta^{13}C$ signatures reflect differences in foraging behavior with depth or spatial extent of movement within central Puget Sound. In contrast, $\delta^{13}C$ ratios of a mature female (430 cm TL) and her neonates found stranded in south Puget Sound were highly depleted (mean $\delta^{13}C$: –20.0‰), reflecting the phytoplankton based food web typical of marine waters on the outer coast. This strongly supports the nursery hypothesis that pregnant females migrate from offshore to protected inshore waters for parturition. Finally, $\delta^{13}C$ ratios of subadult sharks collected from the Strait of Juan de Fuca (mean $\delta^{13}C$: –18.4‰) were intermediate between the Puget Sound subadults and the stranded adult female.

Together these studies aid our understanding of the ecology and behavior of large apex predators in Puget Sound and the Georgia Basin, progress that is crucial to clarifying a broad range of ecosystem interactions and a critical component of any rigorous ecosystem-based management plan.

Genomic biomarkers for assessing fish reproductive health

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Urbanization, coastal population growth, agricultural practices, and climate change have greatly affected water quality throughout our aquatic ecosystems. Many chemicals contaminating fish and aquatic ecosystems are known to disrupt endocrine function, potentially leading to impaired development and reproduction of wildlife and humans. To evaluate relationships between environmental conditions (e.g., reduced food availability, hypoxia, endocrine disrupting chemicals) and fish reproductive health, researchers require modern, comprehensive bioassessment tools. Thus the aim of this research is to develop tools to measure large-scale gene expression in the gonad as a way to assess salmon reproductive health.

In this study, we focused on the effect of feed restriction over a 17-week period on the reproductive health of immature salmon. Prolonged fasting caused regression of the gonads and disrupted the reproductive axis, as fasted salmon showed significantly lower gonad weights and plasma estradiol levels relative to fed animals by week 14. Using suppression subtractive hybridization (SSH), we have identified genes that are putatively up-regulated or down-regulated in normally growing versus regressing ovaries. We have also developed quantitative polymerase chain reaction methods to monitor transcripts for genes involved in programmed cell death that are being measured in ovary samples from this study. Ultimately as we continue this work, including future experiments with other environmental stressors, we plan to utilize the suite of genes identified by SSH and other candidate genes to construct a custom oligonucleotide microarray that will serve as a "fingerprint" for assessing salmon reproductive health in the wild.

Zooplankton biomass and biodiversity in Puget Sound

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Zooplankton are the primary food source for all fish larvae, invertebrates, and many adult fish and mammals in Puget Sound. Despite their importance in the food chain, we know very little about their distribution, abundance, biomass availability, and population variability in Puget Sound. NOAA Fisheries Service is collaborating with the University of Washington and King County to study variability in zooplankton populations in Puget Sound. Monthly sampling is conducted in the main basin of Puget Sound, and biannual samples are collected throughout Puget Sound and the Strait of Juan de Fuca with the Puget Sound Regional Synthesis Model (PRISM) sampling effort. This effort is the first of its kind, and is critical to increasing our understanding of zooplankton and their contribution to the Puget Sound ecosystem. This in turn helps us to better evaluate, manage, and protect Puget Sound.